CHAPTER V. ION-EXCHANGE TEST PROGRAM

Softening water (removal of calcium) through the IX process is a proven technology that has been used in industry for years. The physical design of the Los Banos facility's IX system used hydraulic loading rates similar to those used in typical softeners. The use of RO reject brine for regeneration was studied and successfully tested in pilot investigations (Department of Water Resources, 1978 and 1983; U.S. Bureau of Reclamation, 1983 and 1984). The unique aspects of the Los Banos facility's system were (1) its scale and the need for continuous operation of the system to soften water using desalting reject brine for regeneration and (2) the softening and regeneration of water with very high concentrations of hardness, sodium, and total dissolved solids coupled with high sodium-to-hardness ratio to the degree as required for use in this particular desalting system.

IX test program activities were grouped into two phases. The first phase involved startup of the main units and development of working cycles through main unit operation and testing performed with the bench unit. This phase included modifications, calibration of equipment, and other work needed to ready the main units for continuous operation in concert with the desalting systems. The second phase involved operating the IX system on a continuous basis to supply the desalting systems with softened water and gather information necessary to evaluate the IX process as part of the treatment scheme of desalting agricultural drainage water for reuse. This work included computer program development and minor modifications to the IX system.

Activities performed during each phase of development are summarized below:

Phase I Initial main unit startup
Bench unit testing -- development of working cycles

- Series 100 -- sodium chloride working cycle
- Series 200 -- reject brine working cycle
- Series 300 -- resin capacity tests

Phase II Main unit operations

- Period 1 (June through August 1985)
- Period 2 (January through February 1986)
- Period 3 (May through June 1986)
- Period 4 (July through August 1986)

Initial Main Unit Startup

Testing with the main IX system began in early March 1984. The units were manually operated to (1) test pipelines, valves, and other system equipment and (2) acquire data to help plan the operation schedule of the IX runs that would be necessary when the RO units were put on-line. Pumps and electrically operated valves were checked and adjusted after their prolonged inactivity during clarification and filtration testing. Leaks in piping were detected and repaired, and influent and effluent clearwells and brine processing tanks were flushed and cleaned. The safety relief valves supplied with the units were found to be inappropriately sized and thus were replaced. The laterals of the upper flow distributors, which were covered with PVC screen to prevent resin loss during backwash and regeneration, were plugged by fine sediment and broken resin beads. Unit 1 was cleaned by a local water service firm; Unit 2 was cleaned by plant personnel. Cleaning consisted of backwashing the unit through the top access hole with clarified filtered water until the effluent was clear of sediment and resin. In addition to the plugging of the upper distributors, several of the lower distributor laterals in Column C were found to be broken.

Unit 1 was returned to service in early April after its laterals were repaired and the unit was cleaned. Despite the cleaning, regeneration and backwashing events again led to plugging of the upper distribution lateral screens. Also, a leak was found in the brine tank (T1) and subsequently repaired.

Testing resumed after upper distributor lateral screens were removed. There was no sign of distributor plugging during testing, but both units experienced further mechanical difficulties. A few more lower distributor laterals in one column of both units separated from the distributor, resulting in some loss of IX resin. The units were shut down for repair, and additional resin was ordered to replace the lost resin.

Repairs to the lower distribution laterals were completed in early June 1984, and testing was resumed until June 14, when an additional 1 foot of resin was added to each column.

On June 21, severe oxidation and corrosion were discovered on the galvanized steel bottom collector manifold of IX column D. Since all four columns had been used equally, it was assumed that all bottom manifolds would have to be replaced. To avoid a recurrence of this deterioration, stainless-steel pipes and fittings were ordered for the new manifolds. The screens were plastic. Unit 1 continued in operation until June 29. Data from these initial operations are shown in Table 2.

In July 1984, requirements by the California Department of Fish and Game (to keep additional salt out of the San Luis Drain) resulted in restrictions being placed on plant operations. Testing with the main IX system could not be resumed until the system was modified to eliminate waste (salt) discharges into the San Luis Drain. These modifications, shown on Figure 5, included construction of a brine sump and installation of piping, valves, and other necessary appurtenances. These modifications were completed in February 1985.

A bench-scale unit was designed to simulate operation of the main units, since the main units could not be operated until they were modified. Installation of the bench-scale unit began in late August; testing commenced in early November.

TABLE 2

INITIAL MAIN UNIT STARTUP
OPERATION PARAMETERS AND RESULTS*
March through June 1984

Date	Sodium Chloride Brine Regeneration (volume = 3,750 gallons)		Service				
	Duration (minutes)	Concentration (percent)	Water Type	Duration (minutes)	Total Hardness (meq/L) Influent	Total Hardness (meq/L) Effluent	Resin Capacity (eq/L of resin)
3-28	54	12	Clarifier	70	NA	1.4	NA
3-30	54	12	Clarifier	60	NA	1.2	NA
4-02	58	12	Clarifier	65	NA	1.4	NA
4-02	62	12	Clarifier	60	NA	1.1	NA
4-03	32	12	Clarifier	55	50.6	1.6	0.55
4-03	38	12	Clarifier	60	50.6	1.6	0.60
4-05	40	8	Clarifier	55	NA	1.8	NA
4-07	62	10	Clarifier	60	48.8	1.8	0.58
4-08	56	10	Clarifier	40	51.6	1.8	0.20
5-04	40	11	Clarifier	50	46.6	1.9	0.46
5-05	54	11.2	Clarifier	67	52.2	1.0	0.70
5-06	52	12	Clarifier	60	54.4	1.2	0.66
5-08	52	11.5	Clarifier	65	52.4	1.8	0.68
5-10	53	11.5	Clarifier	55	52.4	1.5	0.57
5-19	50	19	Clarifier	60	52.8	1.0	0.64
5-19	50	12	Clarifier	40	52.8	1.4	0.42
6-11	50	6	Marshpond	NA	58.0	5.4	NA
6-12	50	12	Marshpond	60	56.4	3.4	0.65
6-12	32	12.5	Marshpond	70	56.4	4.0	0.75
6-26	31	10	Clarifier	63	51.2	3.0	0.49
6-26	32	12	Clarifier	18	51.2	3.0	0.14
6-27	44	12	Clarifier	60	52.4	1.0	0.50
6-27	44	12	Clarifier	60	52.4	0.8	0.50
6-27	50	12	Clarifier	60	52.4	1.8	0.49
6-28	50	12	Clarifier	60	50.8	1.0	0.49
6-28	50	12	Clarifier	60	50.8	0.8	0.49

* All service flows were at 230 gpm except on April 8, when it was at 110 gpm.
One foot of resin was added to each column on June 14.

NA = not available.

Bench Unit Testing -- Development of Working Cycles

This portion of Phase I activities involved operation of the bench-scale units at operations parameters similar to those required of the main units. The primary objective of Phase I was to develop a working cycle for both sodium chloride and reject brine regenerations.

The method of experimentation in Phase I was to vary one parameter at a time and collect discrete samples for chemical analysis. The results were then evaluated to observe the effect the parameter variations had on the volume of process water softened and the leakage of calcium.

Additionally, resins from manufacturers other than the supplier for the main IX units were tested on process water taken from the marshponds, the clarifier, and the San Luis Drain. The scope and extent of testing were dictated by results of each test as well as by plant priorities.

Sodium Chloride Working Cycle Experiment (Series 101 Through 126)

The first major task of bench unit testing was to develop a sodium chloride working cycle for use during RO system startup.

The purpose of developing the sodium chloride cycle was to find a combination of independent regeneration parameters (brine contact time and concentration) that would give a consistent service event volume (shown on Figure 6). A secondary objective was to limit the volume of brine and amount of salt used in manufacturing the brine, since space for brine disposal was limited at the plant site.

The development of the sodium chloride cycle involved 26 separate experiments, labeled Experiment Series 101 through 126. The first 12 experiments were single tests that carried the service event past the calcium breakthrough point to determine the volume of process water "softened" for a given regenerant brine concentration. The cycle for these 12 runs consisted of backwash, regeneration, slow rinse, fast rinse, and service steps. The flowrates (per cross-sectional area of bed) used correspond to those used in the main units, and initial event durations were derived from manufacturers' literature. Feedwater came from the marshponds.

Results of the first 12 runs showed that, with upflow regeneration, backwash was not necessary. In fact, this step reduced the amount of water softened. The backwash step, while designed to remove particulates from the resin bed accumulated during service, only further depleted the IX bed. Backwash used clarified, unsoftened water. This step resulted in additional brine being used in regeneration to replace hardness removed during backwash.

The last 14 experiments consisted of operating the bench unit for a number of consecutive cycles to test the resin's ability to continue to soften process water through a number of cycles for a given brine contact time and concentration. The working cycle developed and verified for ten complete runs (Experiment Series 121) consisted of the following events:

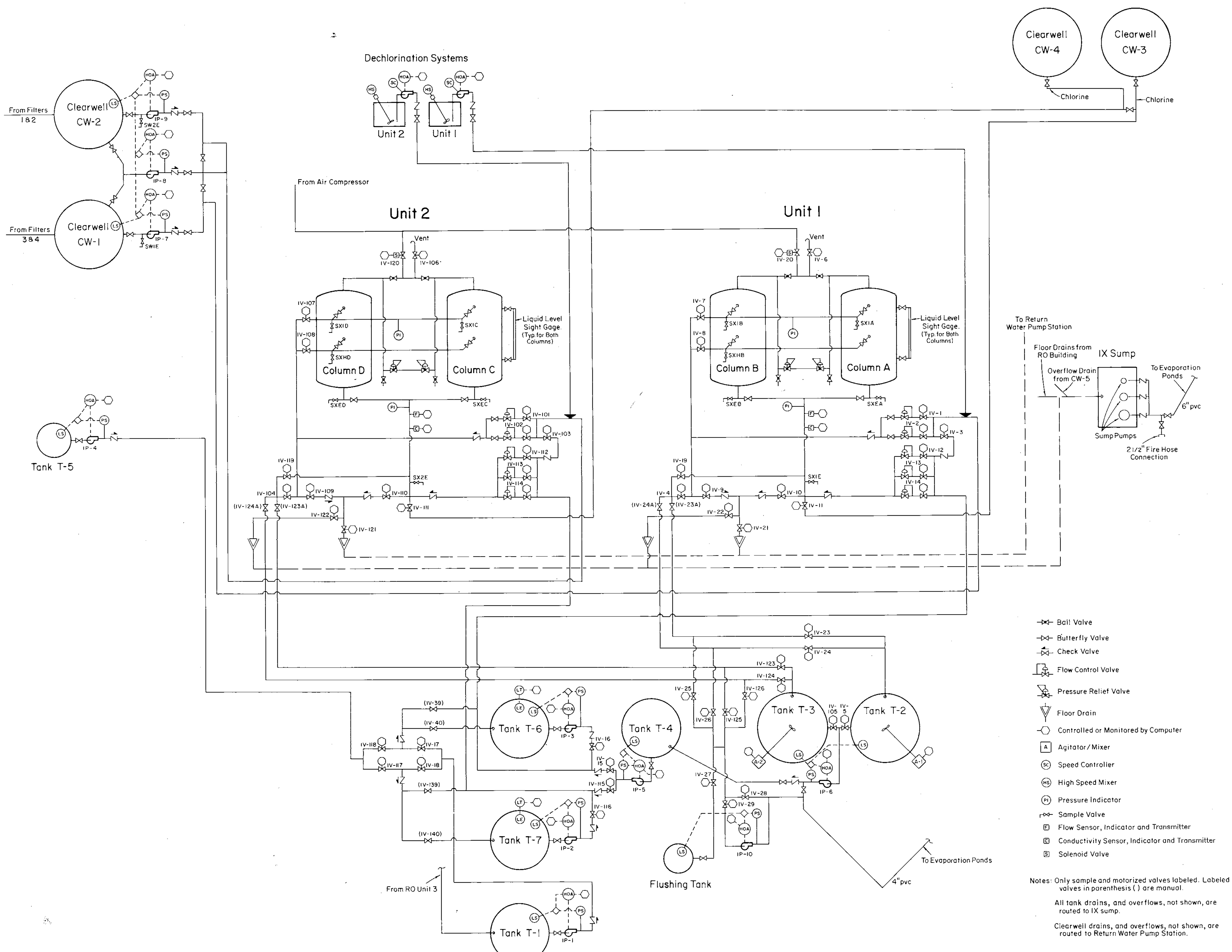
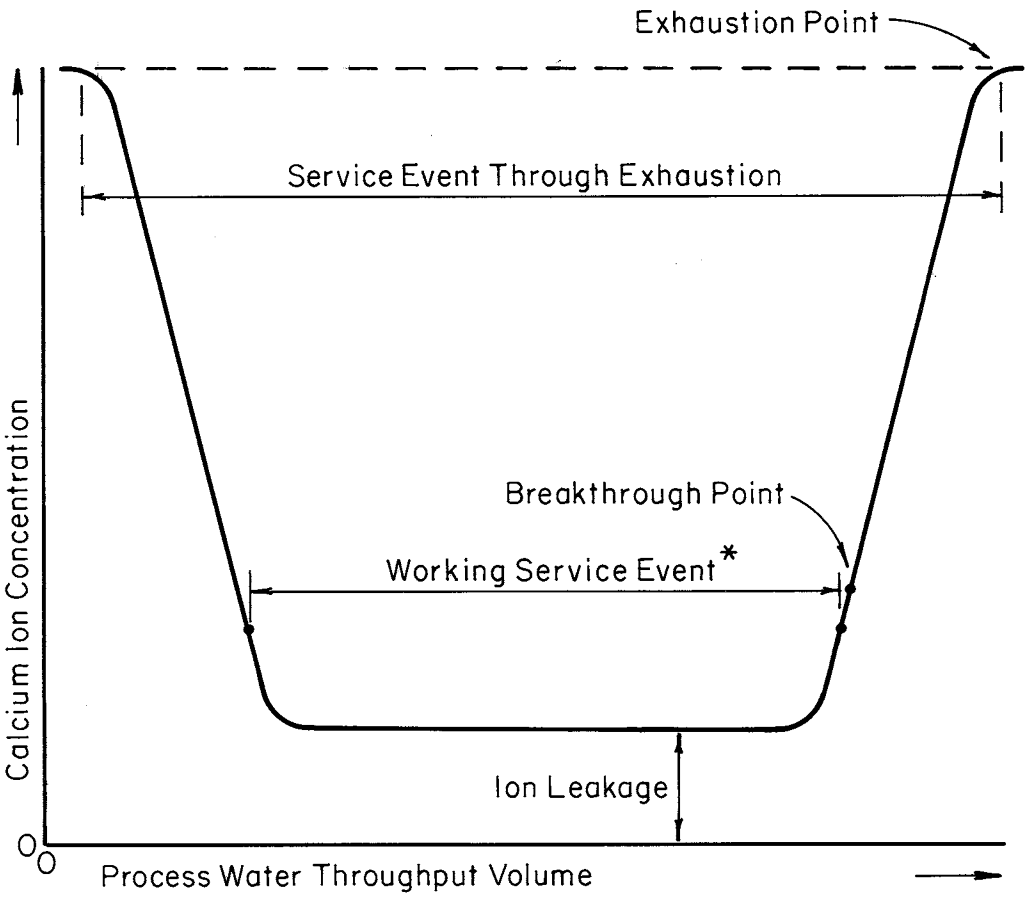


Figure 5.
Los Banos Demonstration Desalting Facility: Ion-Exchange System -- Working Schematic



*Note: The most efficient service event time is not necessarily the time to breakthrough.

Figure 6. Ion Exchange - Idealized Service Event

Event	Duration (minutes)
Regeneration	50*
Slow rinse	5
Fast rinse	15
Service	120

*12-percent brine.

Table 3 (resin performance) and Table 4 (regenerant brine composition) give the results of softening and the regenerant characteristics for the 26-experiment series. Other operational data and chemical analyses are presented in Appendix A.

Reject Brine Working Cycle Experiment (Series 201 Through 210)

The second activity in bench-unit testing involved developing an initial working cycle using brine produced by a desalting process.

Brine used in these tests was generated by a wiped-film rotating-disk evaporator (an evaporative type of desalting unit). This brine was used because RO brine was not available. The rotating evaporator disk (RED) process produced a brine similar to that produced by reverse osmosis, but at a more concentrated level. RED brine was diluted to match the projected concentration of RO brine. The brine for these tests was produced during batch-type operation of the RED.

Ten single-run experiments were conducted with RED brine. The events in this cycle are listed below:

Recycled brine regeneration
Fresh brine regeneration
Slow rinse
Fast rinse
Service

To generate an adequate volume of recycled brine for testing, regeneration for the first three runs was conducted only with fresh brine. Resin tested was taken from the main IX units for all runs except test 208, which used new C20 resin. The last portion of the fast rinse event of the cycle was diverted into a separate rinse tank. This was performed to save a maximum amount of the initial fresh brine and to prevent dilution of the brine with the rinse feedwater. This feature was incorporated into the RO brine cycle of the main units. Operation parameters are shown in Table 5.

Recycled brine tests showed that the integrated softening/regeneration system had the ability to soften process water as required for use in a continuous mode in an RO system. Product calcium leakages, which are indications of the average leakage for a working cycle, ranged between

TABLE 3

BENCH-UNIT SERIES 100 TEST
SOFTENING RESULTS
(sodium chloride brine regeneration)

Experiment Series	Run	Bed Volumes Softened	Resin Leakage (meq/L)		Resin Capacity (eq/L of resin)		Ratio (total to calcium)			Sodium Gained (eq/L of resin)	Ratio (sodium to total hardness)	
			Calcium	Total	Calcium	Total	Capacity	Leakage	Influent		Capacity	Influent
101	a	25.2	0.44	0.96	0.633	1.187	1.88	2.18	1.88	0.439	0.37	2.27
102	a	22.7	0.48	1.18	0.562	1.082	1.93	2.46	1.94	0.395	0.37	2.32
103	a	22.0	0.44	1.12	0.598	1.032	1.73	2.55	1.74	1.054	1.02	2.90
104	a	23.0	0.64	1.42	0.564	1.014	1.80	2.22	1.81	0.998	0.98	2.86
105	a	23.0	0.80	1.28	0.552	1.065	1.93	1.60	1.92	1.601	1.50	3.38
106	a	22.0	0.72	1.12	0.548	1.032	1.88	1.56	1.88	0.670	0.65	2.54
107	a	22.5	0.76	1.16	0.531	1.052	1.98	1.53	1.97	0.977	0.93	2.81
108	a	20.9	0.70	1.48	0.530	0.991	1.87	2.11	1.88	1.002	1.01	2.85
109	a	20.9	0.72	1.62	0.513	0.971	1.89	2.25	1.90	1.184	1.22	3.08
110	a	8.7	0.76	1.80	0.216	0.401	1.86	2.37	1.88	0.264	0.66	2.54
111	a	23.4	0.34	0.64	0.572	1.107	1.94	1.88	1.94	1.118	1.01	2.99
112	a	22.4	0.60	1.12	0.559	1.048	1.88	1.87	1.88	1.264	1.21	3.08
113	a	24.7	0.48	0.84	0.610	1.155	1.89	1.75	1.89	1.074	0.93	3.02
	b	22.0	0.64	1.42	0.540	1.015	1.88	2.22	1.89	0.956	0.94	2.92
	c	18.6	0.76	1.44	0.462	0.859	1.86	1.89	1.86	0.809	0.94	3.02
	d	18.6	0.80	1.56	0.450	0.872	1.94	1.95	1.94	0.648	0.74	2.70
	e	18.3	0.88	1.76	0.419	0.846	2.02	2.00	2.02	0.955	1.13	3.08
114	a	19.0	0.66	1.24	0.435	0.856	1.97	1.88	1.97	0.742	0.87	3.00
	b	19.1	0.70	1.44	0.460	0.874	1.90	2.06	1.90	1.246	1.43	3.32
	c	18.2	0.68	1.66	0.455	0.823	1.81	2.44	1.83	0.793	0.96	3.25
	d	11.1	0.68	1.66	0.268	0.507	1.89	2.44	1.90	0.436	0.86	2.86
	e	16.1	0.64	1.58	0.388	0.732	1.89	2.47	1.90	0.977	1.33	3.23
115	a	13.7	0.74	1.90	0.330	0.638	1.93	2.57	1.95	0.776	1.22	3.06
	b	14.4	1.32	3.04	0.356	0.643	1.81	2.30	1.83	0.817	1.27	3.11
116	a	20.5	0.84	1.44	0.508	0.980	1.93	1.71	1.92	1.160	1.18	3.01
	b	14.0	0.96	2.40	0.344	0.653	1.90	2.50	1.92	0.607	0.93	2.74
	c	21.0	0.64	1.24	0.523	1.005	1.92	1.94	1.92	1.185	1.18	3.01
	d	19.6	0.64	1.44	0.489	0.935	1.91	2.25	1.92	0.937	1.00	2.83
117	a	25.2	0.40	0.38	0.625	1.200	1.92	0.95	1.90	1.096	0.91	2.90
	b	23.2	0.48	1.00	0.574	1.091	1.90	2.08	1.90	1.211	1.11	3.08
	c	23.6	0.68	1.28	0.578	1.102	1.91	1.88	1.90	1.334	1.21	3.17
	d	22.8	0.72	1.08	0.558	1.069	1.92	1.50	1.90	1.288	1.21	3.17
	e	20.9	0.52	1.20	0.515	0.977	1.90	2.31	1.90	1.272	1.30	3.26
118	a	25.7	0.44	0.76	0.779	1.172	1.50	1.73	1.51	1.228	1.05	3.00
	b	23.6	0.52	1.08	0.716	1.071	1.50	2.08	1.51	1.542	1.44	3.37
	c	25.0	0.52	0.96	0.757	1.136	1.50	1.85	1.51	1.522	1.34	3.28
	d	22.8	0.56	1.12	0.691	1.034	1.50	2.00	1.51	1.391	1.34	3.28

TABLE 3 (continued)

BENCH-UNIT SERIES 100 TEST
SOFTENING RESULTS
(sodium chloride brine regeneration)

Experiment Series	Run	Bed Volumes Softened	Resin Leakage (meq/L)		Resin Capacity (eq/L of Resin)		Ratio (total to calcium)			Sodium Gained (eq/L of resin	Ratio (sodium to total hardness)	
			Calcium	Total	Calcium	Total	Capacity	Leakage	Influent		Capacity	Influent
119	a	24.5	0.68	1.20	0.619	1.115	1.80	1.76	1.80	1.915	1.72	3.62
	b	20.7	1.28	2.16	0.511	0.924	1.81	1.69	1.80	1.080	1.17	3.35
	c	23.1	1.12	1.88	0.574	1.036	1.81	1.68	1.80	1.505	1.45	3.44
	d	21.5	1.44	2.04	0.529	0.964	1.82	1.42	1.80	1.405	1.46	3.53
121	a	19.1	0.60	0.92	0.523	0.868	1.66	1.53	1.66	0.706	0.81	2.67
	b	19.1	0.52	0.88	0.525	0.869	1.66	1.69	1.66	0.830	0.96	2.81
	c	18.9	0.88	1.44	0.513	0.851	1.66	1.64	1.66	0.865	1.02	2.86
	d	17.8	0.64	1.16	0.488	0.807	1.65	1.81	1.66	0.737	0.91	2.77
	e	19.6	1.16	1.92	0.525	0.870	1.66	1.66	1.66	1.021	1.17	3.00
	f	19.3	0.60	1.00	0.529	0.876	1.66	1.67	1.66	0.923	1.05	2.91
	g	19.1	0.44	0.76	0.526	0.871	1.66	1.73	1.66	0.789	0.91	2.77
	h	19.1	0.40	0.64	0.526	0.872	1.66	1.60	1.66	0.829	0.95	2.81
	i	19.1	0.68	1.08	0.522	0.865	1.66	1.59	1.66	0.830	0.96	2.81
	j	19.1	0.80	1.20	0.519	0.863	1.66	1.50	1.66	0.996	1.15	3.00
122	a	19.1	1.00	1.80	0.485	0.844	1.74	1.80	1.74	0.955	1.13	3.03
	b	19.1	0.96	1.60	0.486	0.848	1.75	1.67	1.74	0.830	0.98	2.88
	c	18.0	0.92	1.68	0.458	0.796	1.74	1.83	1.74	0.860	1.08	2.98
	d	19.1	1.00	2.04	0.485	0.839	1.73	2.04	1.74	0.664	0.79	2.69
	e	19.1	1.04	1.84	0.484	0.843	1.74	1.77	1.74	0.955	1.13	3.03
123	a	20.1	1.04	1.60	0.517	0.891	1.72	1.54	1.72	0.829	0.93	2.79
	b	19.7	1.28	2.20	0.503	0.863	1.72	1.72	1.72	0.729	0.84	2.69
	c	19.7	1.24	2.16	0.504	0.864	1.72	1.74	1.72	0.814	0.94	2.79
	d	20.0	1.48	2.40	0.506	0.872	1.72	1.62	1.72	0.870	1.00	2.84
	e	19.4	1.24	2.28	0.496	0.849	1.71	1.84	1.72	0.887	1.04	2.88
124	a	21.8	0.32	0.70	0.464	1.110	2.39	2.19	2.39	1.233	1.11	2.98
125	a	27.0	0.24	0.52	0.561	1.402	2.50	2.17	2.50	2.086	1.49	3.38
126	a	24.8	0.80	1.76	0.505	1.194	2.36	2.20	2.36	1.873	1.57	3.65

TABLE 4

BENCH-UNIT SERIES 100 TEST
REGENERANT BRINE COMPOSITION
(sodium chloride brine regeneration)

Series	Run	Calcium (meq/L)	Total Hardness (meq/L)	Sodium (meq/L)	EC (uS/cm)	Turbidity (NTU)	pH	Chloride (meq/L)	Sulfate (meq/L)	Sodium Throughput (eq/L of resin)
101	a	8.20	14.40	1,565.22	126,000	2.6	7.7	2,016.36	6.25	7.728
102	a	10.00	14.80	1,689.57	135,000	3.6	7.8	1,615.06	6.66	8.116
103	a	9.20	14.80	1,608.70	133,900	7.3	7.9	1,728.29	6.04	7.728
104	a	8.40	14.80	1,486.96	133,900	7.1	7.7	1,692.05	6.45	6.349
105	a	9.60	15.20	1,730.43	135,000	7.0	7.7	1,706.15	5.62	7.158
106	a	8.40	13.20	1,178.26	99,000	4.0	7.6	1,201.35	5.41	5.660
107	a	9.20	12.80	1,100.00	94,800	6.0	7.8	1,142.13	5.41	5.137
108	a	8.40	14.40	1,147.83	92,800	5.0	7.6	1,183.87	5.41	5.054
109	a	7.20	12.80	1,091.30	95,000	3.5	7.9	1,178.23	5.00	3.349
110	a	9.60	13.60	1,152.17	96,300	5.7	7.8	1,197.97	5.21	3.844
111	a	8.80	12.40	1,630.43	126,900	2.3	7.8	1,615.06	5.62	8.746
112	a	8.00	12.40	1,013.04	128,000	2.9	7.8	1,691.20	5.41	3.880
113	a	6.40	11.60	1,543.48	94,000	2.0	7.6	1,169.77	4.37	NA
	b	7.20	11.20	1,334.78	94,000	1.3	7.6	1,161.31	4.58	NA
	c	7.20	11.60	1,282.61	94,000	2.5	7.9	1,164.13	4.79	NA
	d	7.20	11.20	1,282.61	98,800	2.5	7.8	1,150.03	4.79	NA
	e	7.00	11.20	956.52	94,000	2.6	7.7	1,141.57	4.79	NA
114	a	6.20	10.40	91.30	12,300	2.9	7.6	1,374.22	3.96	0.273
	b	7.20	10.80	1,152.17	98,100	1.8	7.9	1,550.48	10.62	4.889
	c	6.40	11.20	1,386.96	99,300	1.3	7.7	1,155.67	4.79	5.497
	d	6.40	11.20	1,243.48	99,900	1.6	7.6	1,155.95	4.79	4.596
	e	6.40	10.80	1,204.35	99,900	1.4	7.7	43.71	7.91	4.741
115	a	7.60	12.00	1,017.39	9,400	0.5	7.5	NA	NA	2.851
	b	8.00	12.00	1,117.39	88,800	1.5	7.2	NA	NA	2.982
116	a	10.80	18.00	2,265.22	16,400	1.5	7.6	NA	NA	6.045
	b	10.80	18.00	2,265.22	16,400	1.5	7.6	NA	NA	5.138
	c	10.80	18.00	2,265.22	16,400	1.5	7.6	NA	NA	6.045
	d	10.80	18.00	2,265.52	16,400	1.5	7.6	NA	NA	6.045
117	a	10.00	17.20	2,056.52	150,500	2.9	7.7	NA	NA	6.586
	b	10.00	17.20	2,056.52	150,500	2.9	7.7	NA	NA	6.586
	c	10.00	17.20	2,056.52	150,500	2.9	7.7	NA	NA	6.915
	d	10.00	17.20	2,056.52	150,500	2.9	7.7	NA	NA	6.586
	e	10.00	17.20	2,056.52	150,500	2.9	7.7	NA	NA	6.257
118	a	7.60	11.60	1,252.17	88,000	0.8	7.6	NA	NA	7.001
	b	7.60	11.60	1,252.17	88,000	0.8	7.6	NA	NA	7.307
	c	7.60	11.60	1,252.17	88,000	0.8	7.6	NA	NA	7.428
	d	7.60	11.60	1,252.17	88,000	0.8	7.6	NA	NA	7.181
	UB	91.20	152.00	691.30	62,100	1.2	7.2	NA	NA	

TABLE 4 (continued)

BENCH-UNIT SERIES 100 TEST
REGENERANT BRINE COMPOSITION
(sodium chloride brine regeneration)

Series	Run	Calcium (meq/L)	Total Hardness (meq/L)	Sodium (meq/L)	EC (uS/cm)	Turbidity (NTU)	pH	Chloride (meq/L)	Sulfate (meq/L)	Sodium Throughput (eq/L of resin)
119	a	11.20	16.80	2,282.61	154,300	1.2	7.5	NA	NA	5.563
	b	11.20	16.80	2,282.61	154,300	1.2	7.5	NA	NA	5.563
	c	11.20	16.80	2,282.61	154,300	1.2	7.5	NA	NA	6.120
	d	11.20	16.80	2,282.61	154,300	1.2	7.5	NA	NA	5.531
	e	11.20	16.80	2,282.61	154,300	1.2	7.5	NA	NA	5.565
	UB	136.00	234.00	573.91	62,400	1.6	7.1	NA	NA	
120	a	11.20	18.00	2,108.70	155,000	1.8	7.8	NA	NA	5.895
	b	11.20	18.00	2,108.70	155,000	1.8	7.8	NA	NA	6.167
	c	11.20	18.00	2,108.70	155,000	1.8	7.8	NA	NA	6.046
	d	11.20	18.00	2,108.70	155,000	1.8	7.8	NA	NA	6.016
	e	11.20	18.00	2,108.70	155,000	1.8	7.8	NA	NA	6.319
	UB	174.00	262.00	608.70	73,500	2.5	7.1	NA	NA	
121	a	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	4.943
	b	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.213
	c	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.213
	d	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.213
	e	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.510
	f	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.510
	g	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.510
	h	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.781
	i	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.510
	j	8.40	15.60	2,260.87	15,300	NA	7.7	NA	NA	5.510
122	a	9.20	14.40	1,760.87	134,400	NA	7.6	NA	NA	4.965
	b	9.20	14.40	1,760.87	134,400	NA	7.6	NA	NA	5.133
	c	9.20	14.40	1,760.87	134,400	NA	7.6	NA	NA	4,292
	d	9.20	14.40	1,760.87	134,400	NA	7.6	NA	NA	4.502
	e	9.20	14.40	1,760.87	134,400	NA	7.6	NA	NA	4.502
123	a	8.80	13.60	1,652.17	129,300	1.6	7.8	NA	NA	4.204
	b	8.80	13.60	1,652.17	129,300	1.6	7.8	NA	NA	4.027
	c	8.80	13.60	1,652.17	129,300	1.6	7.8	NA	NA	4.619
	d	8.80	13.60	1,652.17	129,300	1.6	7.8	NA	NA	3.810
	e	8.80	13.60	1,652.17	129,300	1.6	7.8	NA	NA	4.027
124	a	3.80	16.00	3,141.30	168,700	NA	NA	NA	NA	6.176
	UB	162.00	354.00	1,186.96	103,800	NA	NA	NA	NA	
125	a	7.80	20.40	1,273.91	180,100	NA	NA	NA	NA	2.415
	UB	174.00	384.00	1,000.00	165,500	NA	NA	NA	NA	
126	a	9.60	19.60	3,176.09	175,200	NA	NA	NA	NA	5.616
	UB	244.00	600.00	1,169.57	107,100	NA	NA	NA	NA	

EC = electrical conductivity.
NA = not available.
UB = used brine.

TABLE 5

BENCH-UNIT SERIES 200 TEST
OPERATION PARAMETERS
(rotating evaporator disk brine)

Series*	Date	Resin**	Process Water	Hour	Comment
201	3-04-85	C20a	Marsh	12	All regeneration with fresh brine; run to total hardness breakthrough to influent total hardness.
202	3-07-85	C20a	Marsh	10	All regeneration with fresh brine; run to total hardness breakthrough to influent total hardness.
203	3-11-85	C20a	Marsh	10	All regeneration with fresh brine; run to total hardness breakthrough to influent total hardness.
204	3-12-85	C20a	Marsh	10	First run with recycled brine; run to total hardness breakthrough to influent total hardness.
205	3-19-85	C20a	Marsh	9	Second run with recycled brine; run to total hardness breakthrough to influent total hardness.
206	3-25-85	C20a	Marsh	10	Third run with recycled brine; run to total hardness breakthrough to influent total hardness.
207	3-26-85	C20a	Marsh	9	Fourth run with recycled brine; run to total hardness breakthrough to influent total hardness.
208	3-29-85	C20b	Marsh	9	Fifth run with recycled brine; run to total hardness breakthrough to influent total hardness.
209	4-16-85	C20a	Clarifier	9	Sixth run with recycled brine; run duration for 120 minutes.
210	4-24-85	C20a	Clarifier	11	Seventh run with recycled brine; run duration for 120 minutes.

Series*	Recycled Brine Regeneration				Fresh Brine Regeneration					Slow Rinse		Fast Rinse		Service	
	Loading Rate 1 (gpm/ft^2)	Bed Expansion (percent)	Duration (minutes)	Concentration (percent)	Loading Rate 1 (gpm/ft^2)	Bed Expansion (percent)	Duration (minutes)	Concentration (percent)	Temperature (°C)	Loading Rate 1 (gpm/ft^2)	Duration (minutes)	Loading Rate 1 (gpm/ft^2)	Duration (minutes)	Loading Rate 2 (gpm/ft^3)	Duration (minutes)
201	4.89	50	30	7.0	3.77	38	20	7.0	9.5	2.85	5	6.11	15	1.18	190
202	5.00	50	30	7.0	3.77	38	20	7.0	9.0	2.85	5	6.11	15	1.18	207
203	5.68	55	30	7.0	3.65	NA	20	7.0	13.0	3.54	5	5.54	15	1.22	210
204	5.41	55	30	5.5	3.70	40	20	6.5	12.0	2.85	5	5.63	15	1.19	150
205	5.93	top	50	5.0	3.89	37	20	6.5	12.0	5.36	5	5.36	15	1.20	180
206	5.89	top	50	5.0	3.81	35	20	6.5	10.5	2.95	5	5.48	15	1.18	180
207	5.43	50	50	5.0	3.71	30	20	6.5	10.0	3.71	5	5.60	15	1.08	189
208	5.76	50	50	5.0	3.69	30	20	6.5	9.5	4.48	5	5.50	10	1.19	165
209	5.37	50	70	5.0	3.71	37	20	6.5	17.0	3.46	5	5.66	15	1.19	142
210	5.31	40	40	NA	3.85	50	50	6.5	20.0	3.54	5	4.96	15	1.21	120

*All were Run a.

**C20a resin was taken from main IX columns.
C20b resin is new C20 resin that was also used in the first series of tests.

NA = not available.

0.5 and 4.0 milliequivalents per liter (meq/L) for the recycled brine tests. These tests showed that the average leakage could be kept to acceptable levels when adequate amounts of sodium were passed through the bed during regeneration and a minimum brine contact time was maintained. Hardness leakages for a specific process water throughput volume for the test series are shown in Table 6. Detailed operation data, chemical analyses, and other information concerning these tests are included in Appendix B.

Resin Capacity Tests (Series 301 Through 313)

Resin capacity experiments were conducted to (1) determine the effects of various regenerant brines and feed source waters on a resin's total softening capacity and (2) compare the resulting capacities of resins from several manufacturers. Sodium chloride brine, RED brine, and a brine taken from the salt-gradient solar pond were used for regeneration. Water from the marshponds, filtered clarifier, and San Luis Drain was used as feedwater for softening. The resins tested were Rohm and Haas' Amberlite IR 120, Dow Chemical's Dowex HCR-5, and Diamond Shamrock's Duolite C20. The Duolite resin was extracted from the main IX units. The criteria for the resins tested were that they be standard, off-the-shelf, sodium form, gel-type, strong acid cation products with 8-percent cross-linking. Such resins are used for softening in domestic and industrial applications.

The method of operation for the capacity tests called for fully regenerating the resin and running the service event until the effluent total hardness (or leakage) equaled that of the influent and totally exhausted the IX column (see Figure 6). Samples were taken throughout the entire cycle and analyzed for various constituents.

Thirteen tests were conducted to demonstrate the effect of the feedwater's sodium concentration on the resin's ability to soften water. As the feedwater's sodium concentration increased, the resin's ability to remove hardness decreased. The feedwater's sodium ions inhibited the exchange of the feedwater's hardness ions with the resin's sodium ions and resulted in an increase in hardness leakage and a reduction in hardness removal capacity. The same principal applied to regeneration, but the constituents of sodium and hardness were reversed.

The tests also demonstrated the condition of the main unit's resin. There was concern that the main unit's resin had become fouled, either biologically or with iron, or had degraded due to past tests or through the prolonged inactivity of the system. The main unit's resin performed as well as new resin. Results for the tests are shown below in Table 7. Detailed operation data, chemical analyses, and other information concerning these tests are included in Appendix C.

TABLE 6

BENCH-UNIT SERIES 200 TEST
HARDNESS LEAKAGE VS. THROUGHPUT
(rotating evaporator disk brine regeneration)

Series	Run	Type	Influent	Product Water*	Instantaneous Hardness Leakages at Throughput During Service (meq/L)													
	a	Calcium	27.40	0.56	0.48	0.60	0.52	0.52	0.48	0.44	0.48	0.48	0.68	0.80	0.88	2.00	3.00	3.40
201		Total hardness	52.60	0.80	0.76	0.76	0.72	0.72	0.84	0.76	0.80	0.92	1.44	2.00	3.92	9.20	19.00	26.00
	Throughput	Bed volume	NA	19.7	1.6	5.2	7.9	11.0	15.0	18.1	19.7	21.3	22.1	23.7	25.2	26.8	28.4	30.0
	a	Calcium	29.20	0.80	0.64	0.72	0.64	0.60	1.20	2.80	5.40	9.00						
202		Total hardness	46.80	1.56	1.52	1.32	1.32	1.70	10.80	24.80	33.90	41.20						
	Throughput	Bed volume	NA	22.1	3.3	5.4	15.1	21.5	24.0	27.1	30.0	32.7						
	a	Calcium	34.40	0.68	0.68	0.64	0.64	0.64	0.64	0.68	1.40	2.88	7.40	9.20	11.60			
203		Total hardness	46.80	1.48	1.28	1.24	1.28	1.28	1.28	2.28	10.28	26.20	32.80	41.20	43.00			
	Throughput	Bed volume	NA	19.6	1.6	4.9	8.2	11.9	17.1	21.2	24.5	26.9	29.4	31.8	34.3			
	a	Calcium	24.80	4.00	2.04	1.80	1.20	1.24	1.36	1.68	3.00	6.40	11.00					
204		Total hardness	45.80	15.64	4.16	2.64	2.40	2.52	2.56	5.12	15.12	29.60	39.60					
	Throughput	Bed volume	NA	19.1	0.0	1.6	4.8	8.0	11.1	16.7	19.1	21.3	23.9					
	a	Calcium	25.00	2.16	1.56	0.96	0.88	0.96	0.88	1.04	1.76	3.52	6.80	9.00	10.80	13.00		
205		Total hardness	46.40	12.00	3.44	2.08	1.88	1.88	2.08	4.96	13.60	24.80	35.40	40.40	42.00	44.00		
	Throughput	Bed volume	NA	19.2	0.0	0.8	4.8	8.0	11.2	17.6	19.2	21.7	24.1	25.7	27.3	28.9		
	a	Calcium	27.60	1.28	1.40	1.16	1.08	1.12	1.24	1.12	1.20	1.28	1.68	2.84	5.60	7.40	10.40	
206		Total hardness	50.00	3.44	2.96	2.68	2.56	2.60	2.56	2.84	3.44	4.32	9.52	21.00	34.60	38.80	42.40	
	Throughput	Bed volume	NA	18.9	0.0	1.6	2.4	4.7	7.9	11.8	15.8	17.1	18.9	21.3	23.7	26.1	28.4	
	a	Calcium	26.20	1.40	1.68	1.28	1.36	1.24	1.28	1.40	1.40	6.60	10.40	11.20				
207		Total hardness	47.20	4.20	3.76	2.88	3.28	2.96	3.12	4.12	29.60	35.80	41.00	43.00				
	Throughput	Bed volume	NA	18.7	0.0	2.2	4.3	7.2	10.1	15.1	21.6	19.6	25.9	27.2				
	a	Calcium	25.60	2.08	1.68	1.52	1.44	1.52	1.68	1.80	2.88	4.20	7.00	9.60	13.40			
208		Total hardness	46.80	7.80	3.52	3.80	3.80	3.80	4.12	6.72	16.24	27.00	35.60	41.00	45.20			
	Throughput	Bed volume	NA	19.2	0.8	2.4	4.8	8.0	11.2	14.8	17.6	19.2	21.5	23.9	26.3			
	a	Calcium	26.80	1.04	0.88	0.76	0.76	0.80	0.76	1.28	2.28	3.60						
209		Total hardness	48.40	3.40	2.32	2.32	2.16	2.32	2.40	NA	24.80	31.40						
	Throughput	Bed volume	NA	19.2	0.0	1.6	6.4	11.2	12.8	19.2	20.7	22.7						
	a	Calcium	27.20	0.48	0.50	0.46	0.36	0.36	0.44									
210		Total hardness	51.60	1.04	1.04	1.00	0.80	0.88	1.24									
	Throughput	Bed volume	NA	19.4	0.0	1.6	9.7	14.6	19.4									

*Analysis of sample taken from the entire service batch 120 minutes after being mixed. Other readings are instantaneous.

NA = not available.

TABLE 7

BENCH-UNIT SERIES 300 TEST
RESIN CAPACITY RESULTS

Test Number	Regenerant Brine	Process Water	Resin Type[1]	Process Water Influent (meq/L)			Resin Capacity (eq/L of resin)	
				Calcium	Total	Sodium	Calcium	Total
301	RED	Marshpond	C20-1	35.0	91.6	196.5	0.45	1.09
302	RED	Marshpond	C20-2	31.0	94.7	196.5	0.37	1.11
303	NaCl	Marshpond	C20-1	35.4	89.0	209.6	0.49	1.17
304	NaCl	Filtered clarifier	C20-1	26.4	50.8	122.3	0.90	1.51
305	NaCl	Filtered clarifier	C20-2	26.3	52.1	117.9	1.06	1.91
306	NaCl	San Luis Drain	C20-2	28.9	52.8	109.2	0.88	1.52
307	NaCl	San Luis Drain	C20-1	31.8	54.2	78.6	1.08	1.69
308	NaCl	San Luis Drain	C20-2	28.0	53.0	480.4[2]	0.84	1.46
309	None[3]	Filtered clarifier	HCR-S	22.0	40.9	78.6	0.74	1.38
310	None[3]	Filtered clarifier	IR 120	21.5	39.9	74.2	1.20	1.73
311	RED	Filtered clarifier	C20-2	25.2	41.4	96.1	1.05	1.68
312	RED	Filtered clarifier	IR 120	23.1	42.3	104.8	0.85	1.50
313	Solar pond	Filtered clarifier	C20-2	27.4	41.7	74.2	1.04	1.42

[1]C20-1 is resin taken from main Unit 1; C20-2 is resin taken from main Unit 2.
[2]Sodium analysis was noted questionable by laboratory.
[3]New resin was used in testing (no regeneration).

Main Unit Operations

There were four periods during which the IX system was operated for prolonged periods to provide soft water for desalting units. Operation of the IX system for Period 1 (June through August 1985) involved regeneration with NaCl brine. The remaining three periods (Periods 2, 3, and 4 -- January through February 1986, May through June 1986, and July through August 1986, respectively) involved regeneration with brine derived from desalting processes. The IX system was operated manually in Period 1 and automatically in Periods 2, 3, and 4.

The chemical concentrations of total hardness (TH), calcium (Ca), and sodium (Na) in the process influent water for the four periods of operation are shown on Figures 7, 8, 9, and 10. The TH and Ca concentrations remained relatively constant at around 50 and 24 meq/L, respectively, until Period 4 when they decreased and eventually leveled to around 12 and 7 meq/L. The decrease was due to the halting of Westlands Water District's subsurface drainage discharges into the San Luis Drain and the flushing of the drain with "fresh" Delta-Mendota Canal water. The Na concentrations fluctuated throughout the course of each period. As Figure 11 shows, the constituent trends tended to match the overall historical monthly San Luis Drain concentration trends.

Figure 7
IX Influent Process Water TH, Ca and Na Conc.
June, July and August, 1985

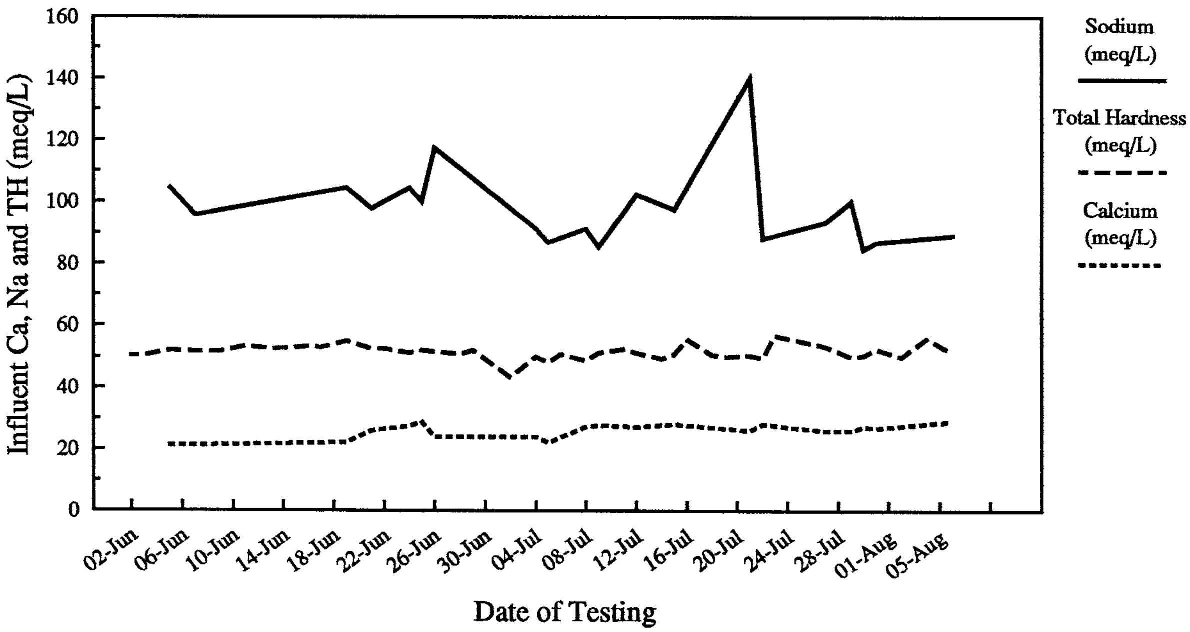


Figure 8
IX Influent Process Water TH, Ca and Na Conc.
January and Febuary, 1986

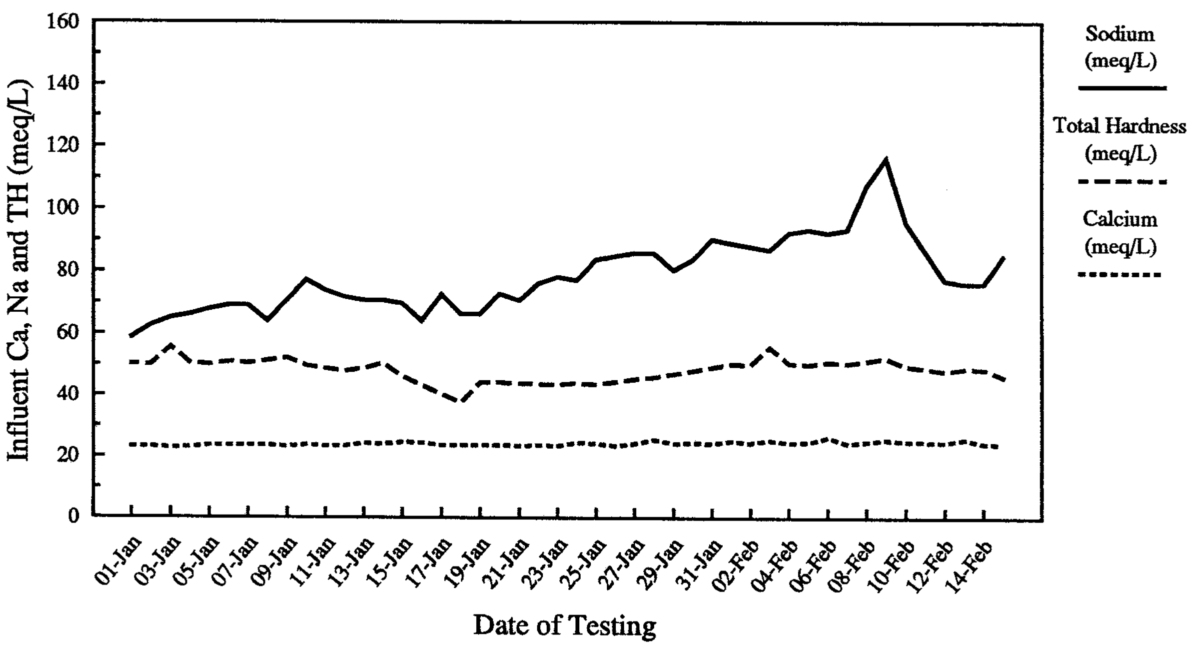


Figure 9
IX Influent Process Water TH, Ca and Na Conc.
May and June, 1986

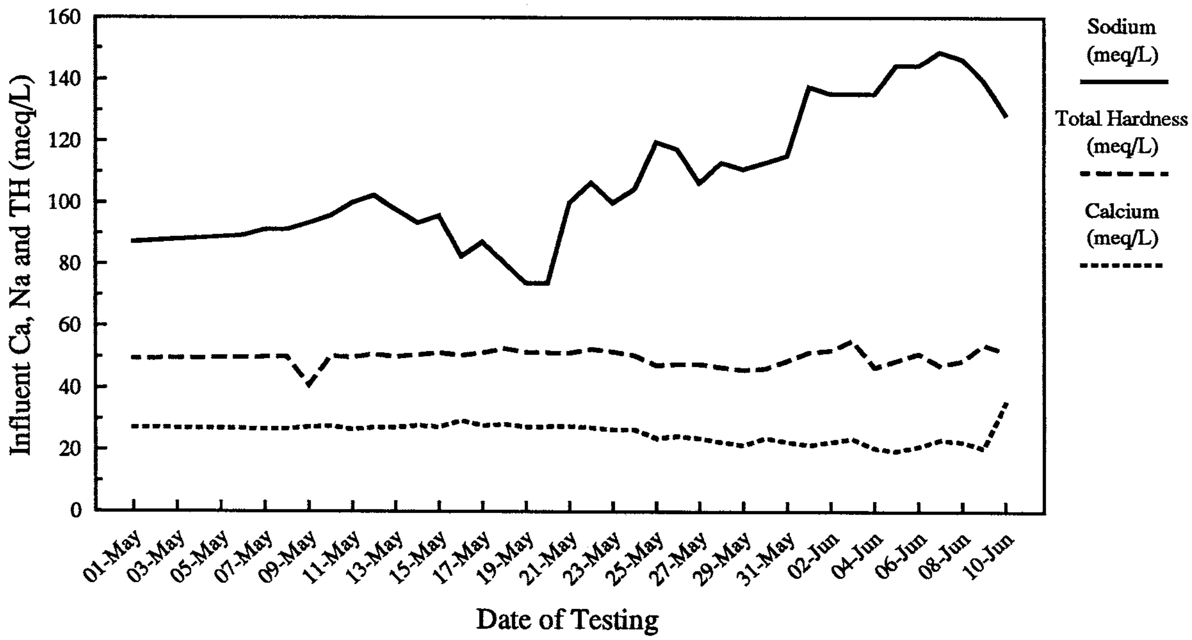


Figure 10
IX Influent Process Water TH, Ca and Na Conc.
July and August, 1986

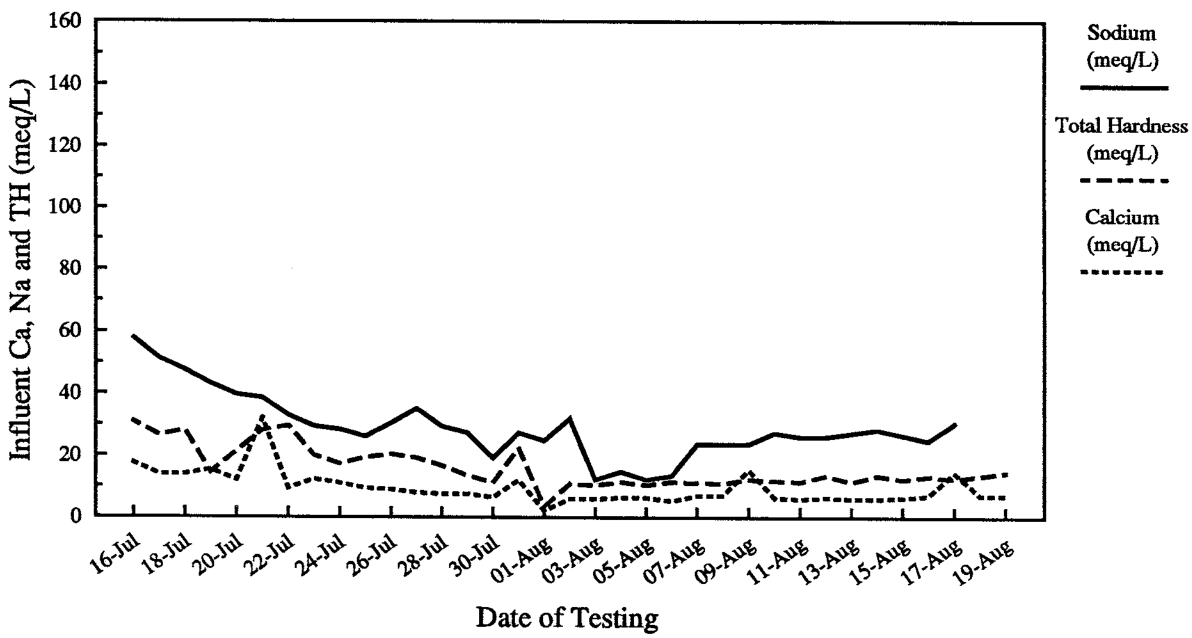
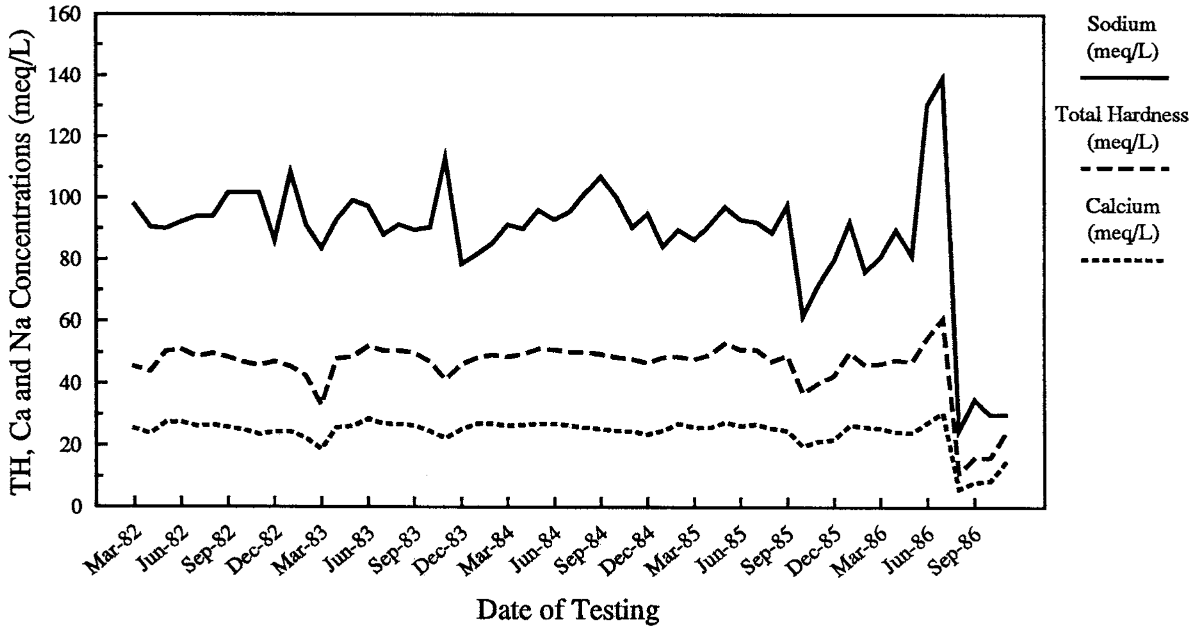


Figure 11
Monthly San Luis Drain TH, Ca, and Na Conc.
March 1982 through November 1986



Period 1 (June Through August 1985)

The main units were put into manual operation in June 1985. Period 1 operations formed (1) a baseline against which the results of other operation periods could be compared and (2) a basis for the computer control programs in the periods of automatic operation that came later. Regeneration was performed with specific volumes and concentrations of sodium chloride brine determined by the bench-unit tests.

Period 1 operation was initiated to verify and further develop the sodium chloride cycle as determined by the bench tests. The period coincided with the startup of a small (10-gpm) RO unit supplied by Hydranautics Water Systems, Inc., which was operated for 1,500 hours as a final check of pretreatment operations performance.

Since the check required softened water, the IX system was operated manually to supply it. (The IX control program for automatic operation was not complete at the beginning of the test program.) Only one IX unit had to be in operation to deliver the required flow. This allowed plenty of time for researchers to collect operational data and experiment with IX procedures.

Unit 1 supplied soft water to the Hydranautics RO unit by gravity flow. Unit 2 was operated periodically to fill clearwell 4 for use when Unit 1 was regenerating. Service ended when calcium leakage passed 1.0 meq/L. The basic schedule for operations is shown in Table 8. Other pertinent information was recorded throughout the entire cycle.

TABLE 8

ION-EXCHANGE OPERATIONS SCHEDULE
MANUAL OPERATIONS
(sodium chloride brine regeneration,
regeneration flow at 75 gpm with 12 percent brine)

Used brine to IX sump
Rinses A and B to IX sump

Rinse C to RWPS
Service to RO

Event Number	Event Description	Duration (minutes)	Component Operation (valve open)		Process Flow		
			Unit 1	Unit 2	Unit	From	To
1	Recirculation of NaCl brine	20	IP 3 IV 16, 39m, 40m	IP 2 IV 116, 139m, 140m	1 2	T6 T6	T6 T6
Recirculation to be performed just prior to regeneration.							
2	Drain	3	IV 6, 10, 22	IV 106, 110, 122	1 2	T6 T7	RWPS RWPS
Columns to be three-quarters full of liquid at end of event.							
3	NaCl brine regeneration	*	IP 3 IV 16, 14, 7, 9, 21	IP 2 IV 116, 114, 107, 109, 121	1 2	T6 T7	IX sump IX sump
4	Drain	3	IV 6, 10, 21	IV 106, 110, 121	1 2	T6 T7	IX sump IX sump
Columns to be three-quarters full of liquid at end of event.							
5	Rinse A	5	IP 7, DP 1 IV 1, 7, 10, 21	IP 9, DP 2 IV 101, 107, 110, 121	1 2	CW1 CW2	IX sump IX sump
6	Rinse B	10	IP 7, DP 1 IV 2, 7, 10, 21	IP 9, DP 2 IV 102, 107, 110, 121	1 2	CW1 CW2	IX sump IX sump
7	Rinse C	**	IP 7, DP 1 IV 2, 7, 10, 22	IP 9, DP2 IV 102, 107, 110, 122	1 2	CW1 CW2	RWPS RWPS
8	Service	***	IP 7, DP 1 IV 1, 7, 11	IP 9, DP 2 IV 101, 107, 111	1 2	CW1 CW2	RO unit RO unit
9	Set-up for regeneration		IP 4 IV 118	IP 4 IV 117	1 2	T5 T5	T6 T7
To be performed manually during service event.							

* Regeneration calls for using 3,740 gallons (2 feet, 10 inches of tank depth for tanks T6 and T7) of 12 percent brine. If at the end of 50 minutes less than 2 feet, 10 inches of brine was used, extend regeneration duration to encompass the entire 2 feet, 10 inches. If less than 12 percent brine was used for regeneration, extend regeneration duration an additional 3.5 inches for every percent reduction of brine concentration. Record all pertinent information of data sheet.

** Duration to be determined in field. Event ends when calcium leakage is less than 50 mg/L as $CaCO_3$.

*** Total service volume is expected to be 27,600 gallons.

Key

A	agitator mixer	IX	ion exchange
CW	clearwell	NaCl	sodium chloride
DP	dechlorination pump	RWPS	return water pump station
IP	ion-exchange pump	T	brine tank
IV	ion-exchange valve		

Problems were experienced in the making of sodium chloride regeneration brine. Although a special mixing-recirculation process was developed, it did not always mix the brine completely. The process consisted of pumping the layered fresh water and saturated brine contents of the mixing tank (T6 or T7) through a maze of piping and back into the mixing tank.

The results of Period 1 operations are shown in Table 9 and on Figures 12 and 13. Figure 12 shows that calcium leakage remained below 1.0 meq/L even though the sodium throughput fluctuated during regeneration. Figure 13 shows the volume of process water that was softened and the concentration of the regenerant brine as determined by two different methods. For operation, the salinity of the brine was determined on site with a hydrometer; the actual sodium content was determined in a laboratory by atomic adsorption spectroscopy. As shown on Figure 13, the actual sodium content and resulting total sodium throughput in regeneration varied for a relatively constant hydrometer measurement of 12 percent.

Other operation parameters developed in Period 1 included initial rinsing requirements and verification of flowrates through the flow control valves. Service, regeneration, and operator's log data are shown in Appendix D.

Period 2 (January Through February 1986)

The main units were restarted on January 2, 1986, to supply the RO unit with softened feedwater. This restarting was the first attempt to operate the system automatically with the Analog Devices, Inc., MACSYM computer. The system remained in operation until shutdown on February 17, when resin was found in the cartridge filters downstream from the IX units.

The objectives of Period 2 operations were to debug the system, further develop rinsing requirements, and provide low-calcium water to the RO units. As Table 10 shows, the units were operated on a conservative cycle to pass a more-than-adequate amount of sodium through the bed during regeneration for the volume of water to be softened. As data were collected and experience developed, the amount of sodium passed through the bed during regeneration was reduced to develop an efficient operation cycle. Initially, event durations were determined by bench unit and Period 1 test results and adjusted as required. Brine used for regeneration was pumped over from the south solar pond, which was acting as a holding pond for plant reject brine.

There were numerous shutdowns because of equipment failure and computer program development. Along with the passage of resin from the IX columns, other problems encountered included brine leaks from tanks T1 and T7 and precipitation of calcium sulfate in the recycled brine tank T4. These tanks were drained, cleaned, and repaired. Tanks T6 and T7 were not required for the reject brine mode of operations; therefore, they were taken out of the operations program. Resin was found to be leaking from a lower manifold of one IX column. The plastic screens on the underdrain laterals had eroded from the repetitive cycles and high velocities. The PVC screens were replaced with stainless-steel screens on all laterals of both units.

TABLE 9

MAIN UNIT OPERATIONS
PERIOD 1 RESULTS
June, July, and August 1985

Date	Softening									Regeneration			Ratio of Soft Water Produced to Sodium Throughput in Regeneration
	Ion-Exchange Influent (meq/L)				Ion-Exchange Effluent (meq/L)		Resin Operating Capacity (eq/L of resin)		Soft Water Produced (bed volume)	Sodium Chloride Brine		Total Sodium Throughput (eq/L of resin)	
	Total Hardness	Calcium	Sodium	Ratio of Sodium to Total Hardness	Total	Calcium	Total Hardness	Calcium		Sodium (meq/L)	EC (μS/cm)		
6-02	50.40	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6-03	50.40	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6-05	52.00	21.20	104.35	2.0	NA	0.58	NA	0.321	15.6	3,217.4	168,100	8.836	1.76
6-07	51.60	21.20	96.65	1.9	NA	0.62	NA	0.319	15.5	2,678.0	155,600	7.603	2.04
6-09	51.60	NA	NA	NA	NA	0.62	NA	NA	3.4	NA	NA	NA	NA
6-09	51.60	NA	NA	NA	NA	NA	NA	NA	14.6	NA	NA	NA	NA
6-11	53.20	NA	NA	NA	NA	0.52	NA	NA	8.4	NA	NA	NA	NA
6-12	52.80	NA	NA	NA	NA	0.46	NA	NA	NA	1,730.4	160,200	4.896	NA
6-13	52.40	NA	NA	NA	NA	0.56	NA	NA	14.2	NA	NA	NA	NA
6-15	52.80	NA	NA	NA	NA	NA	NA	NA	10.6	NA	NA	NA	NA
6-16	53.20	NA	NA	NA	NA	0.56	NA	NA	9.8	NA	NA	NA	NA
6-17	52.80	NA	NA	NA	NA	0.50	NA	NA	13.6	NA	NA	NA	NA
6-19	54.80	22.00	104.35	1.9	NA	0.52	NA	0.357	16.6	2,904.3	161,300	8.218	2.02
6-21	52.40	26.00	97.83	1.9	NA	0.58	NA	0.342	13.5	3,382.6	156,200	9.571	1.41
6-22	52.40	NA	NA	NA	NA	0.56	NA	NA	13.6	NA	NA	NA	NA
6-24	51.20	27.40	104.35	2.0	NA	0.46	NA	0.153	5.7	2,817.4	156,600	7.972	0.71
6-25	52.00	29.00	100.00	1.9	NA	0.64	NA	0.400	14.1	2,695.7	153,400	7.628	1.85
6-29	50.80	24.00	117.39	2.3	NA	0.30	NA	0.432	18.2	3,321.7	153,000	8.293	2.20
6-29	52.00	NA	NA	NA	NA	0.60	NA	NA	14.0	NA	NA	NA	NA
7-02	43.20	NA	NA	NA	NA	0.42	NA	NA	15.7	NA	NA	NA	NA
7-04	50.00	24.00	91.30	1.8	NA	0.60	NA	0.366	15.7	2,013.0	149,000	5.696	2.75
7-05	48.00	22.00	86.96	1.8	NA	0.62	NA	0.308	14.4	2,147.8	157,300	6.077	2.37
7-06	50.80	NA	NA	NA	NA	0.52	NA	NA	13.4	NA	NA	NA	NA
7-08	48.60	27.20	91.30	1.9	NA	0.62	NA	0.357	13.4	2,069.6	147,400	5.856	2.29
7-09	51.20	27.60	85.43	1.7	NA	0.62	NA	0.397	14.7	2,556.5	155,300	6.808	2.16
7-11	52.40	NA	NA	NA	NA	0.50	NA	NA	13.0	NA	NA	NA	NA
7-12	51.20	27.20	102.17	2.0	NA	0.62	NA	0.348	13.1	2,060.9	148,200	5.831	2.24
7-14	49.20	NA	NA	NA	NA	0.56	NA	NA	12.2	NA	NA	NA	NA
7-15	50.80	28.00	97.61	1.9	NA	0.64	NA	0.261	9.5	2,615.2	159,200	6.312	1.51
7-16	55.40	NA	NA	NA	0.70	NA	1.049	NA	19.2	NA	NA	NA	NA
7-18	50.60	NA	NA	NA	1.26	NA	0.826	NA	16.7	NA	NA	NA	NA
7-19	50.00	NA	NA	NA	1.26	0.72	0.723	NA	14.8	NA	NA	NA	NA
7-21	50.40	26.00	140.00	2.8	0.70	0.44	0.786	0.404	15.8	2,087.0	136,600	5.905	2.68
7-22	49.60	28.00	88.26	1.8	NA	NA	NA	NA	NA	3,543.5	179,500	10.027	NA
7-23	56.80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7-27	53.20	26.00	93.48	1.8	0.84	0.56	0.755	0.367	14.4	2,217.4	131,000	6.274	2.30
7-29	50.00	26.00	100.00	2.0	1.04	0.56	0.658	0.342	13.4	2,087.0	127,600	5.905	2.28
7-30	50.40	27.20	84.78	1.7	NA	NA	NA	NA	NA	1,956.5	123,300	5.699	NA
7-31	52.40	26.80	86.96	1.7	0.92	0.54	0.818	0.417	15.9	2,217.4	160,200	6.274	2.53
8-02	50.00	NA	NA	NA	0.92	0.52	0.657	NA	13.4	NA	NA	NA	NA
8-04	56.00	NA	NA	NA	0.90	0.56	0.855	NA	15.5	NA	NA	NA	NA
8-05	NA	NA	NA	NA	0.90	0.72	NA	NA	15.5	3,217.4	168,100	8.301	1.87
8-06	51.20	29.20	89.13	1.7	1.08	0.72	1.025	0.582	20.4	2,217.4	153,000	6.274	3.26

EC = electrical conductivity.
NA = not available.

Figure 12: Resin Capacity and Calcium Leakage Resulting from Sodium Throughput in Regeneration June, July and August, 1985

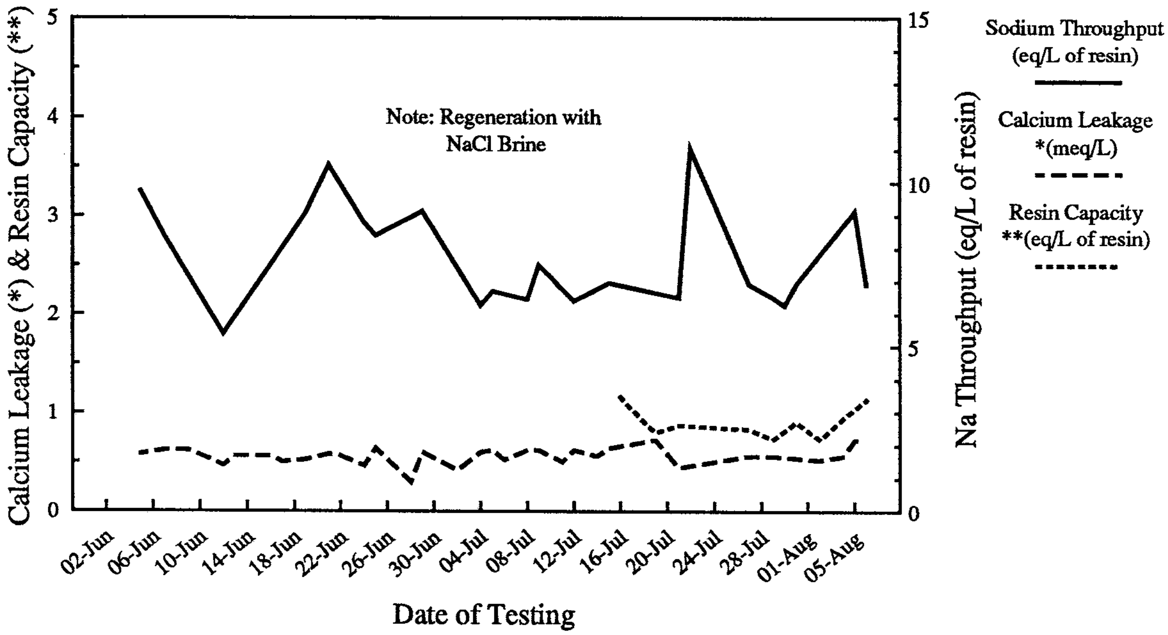


Figure 13: Volume of Softened Water Produced Resulting from Sodium Throughput in Regeneration June, July and August, 1985

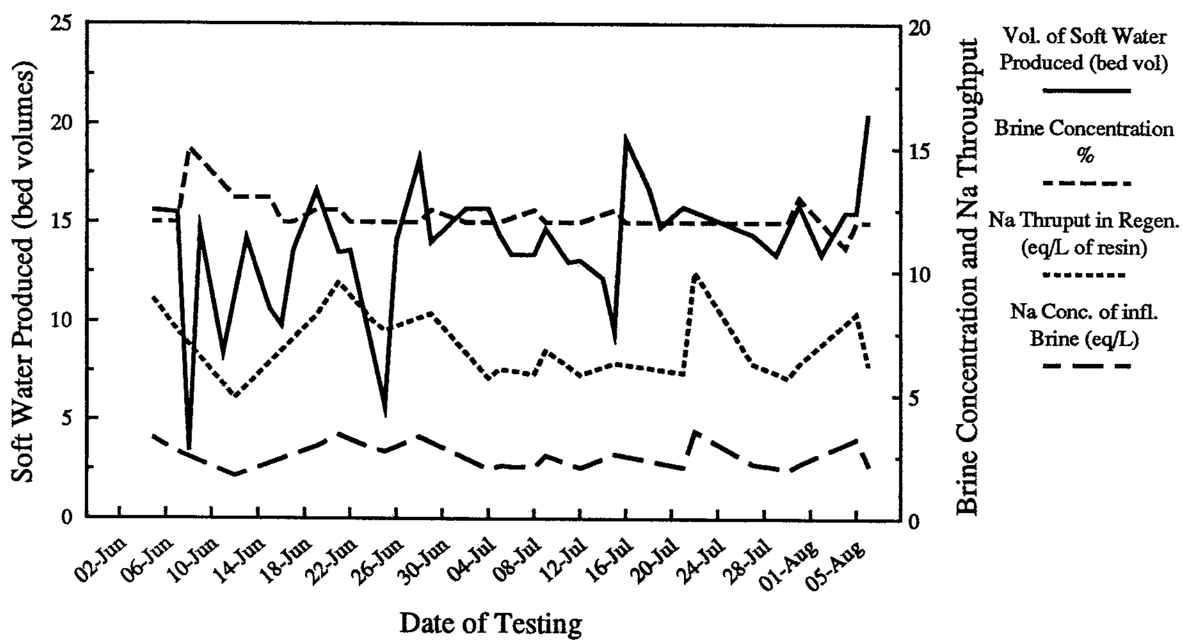


TABLE 10

ION-EXCHANGE OPERATIONS SCHEDULE*
PERIOD 2
(reverse osmosis/electrodialysis brine regeneration,
service flow at 110 gpm)

Waste brine to IX sump
Used brine to T2 or T3
Rinse to IX sump

December 3, 1985

Event Number	Event Description	Duration (minutes)	Component Operation (valve open)		Process Flow		
			Unit 1	Unit 2	Unit	From	To
1	Recycled brine regeneration 1	14	IP 5 IV 15, 12, 7, 9, 22	IP 5 IV 115, 112, 107, 109, 122	1 2	T4 T4	IX sump IX sump
2	Recycled brine regeneration 2	27	IP 5 IV 15, 12, 7, 4, 23	IP 5 IV 115, 112, 107, 104, 123	1 2	T4 T4	T2 T3
3	Fresh brine regeneration	9	IP 3 IV 16, 13, 7, 4, 23	IP 2 IV 116, 113, 107, 104, 123	1 2	T6 T7	T2 T3
4	Rinse A	5	IP 7 IV 1, 7, 19, 23	IP 9 IV 101, 107, 119, 123	1 2	CW1 CW2	T2 T3
5	Rinse B	4	IP 7 IV 2, 7, 19, 23	IP 9 IV 102, 107, 119, 123	1 2	CW1 CW2	T2 T3
6	Rinse C	11	IP 7 IV 2, 7, 10, 22	IP 9 IV 102, 107, 110, 122	1 2	CW1 CW2	IX sump IX sump
7	Rinse D	0	IP 7 IV 2, 7, 10, 21	IP 9 IV 102, 107, 110, 121	1 2	CW1 CW2	RWPS RWPS
8	Service	190	IP 7 IV 1, 7, 11	IP 9 IV 101, 107, 111	1 2	CW1 CW2	CW5 CW5
9	Mixing in T2 or T3	35	A 1	A 2	1 2	Mixing in T2** Mixing in T3**	
10	Set-up for regeneration	40	IP 6 IV 5	IP 6 IV 105	1 2	T2 T3	T4** T4**
11	Set-up for regeneration	6	IP 1 IV 17	IP 1 IV 18	1 2	T1 T1	T6** T7**
12	Drain	3	IV 6, 10, 21	IV 106, 110, 121	1 2	Unit 1 Unit 2	RWPS RWPS

* Error flag: incorrect operation schedule for service flow.
Revised from November 11, 1985 schedule.
Connecting line from CW2 to CW1 open.

** To be performed during service event.

Key

A	agitator mixer	IV	ion-exchange valve
CW	clearwell	IX	ion exchange
DP	dechlorination pump	RWPS	return water pump station
IP	ion-exchange pump	T	brine tank

Table 11 and Figure 14 present the results of Period 2 operations. Calcium leakage remained relatively stable at around 1.0 meq/L until near the end of the period when a gradual increase in leakage occurred. The increase is believed to be a result of the reduction of sodium throughput and the passage of calcium sulfate precipitate through the unit during regeneration.

It should be noted that, for all computer operations, process water effluent volumes (and resulting concentrated ions) included water used for chlorination along with any other water (brine) that inadvertently found its way into the effluent tank. Chlorination water was a combination of RO product water and City of Los Banos water. Flowrates required for chlorination injection were in the range of 7 through 12 gpm as compared to service flow of 110 gpm.

Detailed daily logs which describe the problems encountered in operations and other data collected during Period 2 are located in Appendix E.

Period 3 (May Through June 1986)

The IX and RO systems were restarted in early May following repairs to the columns, initiating a six-week test plan. The objective of the plan was to complete the loop of softening feedwater used in the desalting process and using the reject brine from the desalting process for regeneration of the IX process.

Period 3 operations were a continuation of Period 2 operations, and the IX system was coordinated with the RO units. The purpose of this coordination was to use, during a cycle, the entire volume of reject brine produced by the third-stage desalting unit for the fresh brine regenerant volume -- a minimum of 1 bed volume. The operations schedule for Period 3 is shown in Table 12. The service flowrate was 110 gpm until May 27, when it was increased to 230 gpm.

During Period 3, numerous shutdowns occurred due to service pump bearing failure, valve malfunctions, periodic brine shortages, computer program malfunctions, and problems with the electrodialysis (EDR) unit. By June, most of these problems were overcome and a host of new options were added to the computer operations program to make it more flexible. These options allowed for:

1. Transfer of recycled brine from mixing tanks T2 and T3 to the recycled brine tank (T4) without interrupting the other activities the computer was performing.
2. Choice of a single or continuous cycle.
3. Selection of service pumps.
4. Choice of service flowrates of 110 or 230 gpm.
5. Delay of regeneration to allow for service to begin directly after regeneration and rinse.
6. Choice of brine line from IX unit to mixing tank.
7. Choice of recycled brine regeneration flowrates of 150 or 200 gpm.
8. Choice of fresh brine regeneration flowrates of 75 or 150 gpm.

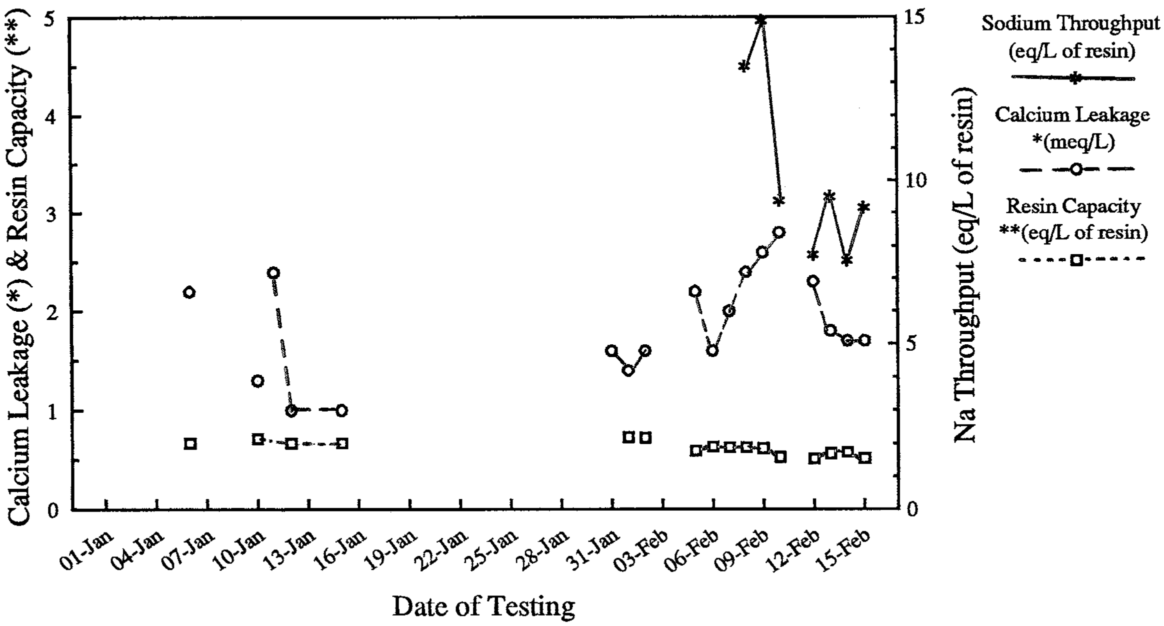
TABLE 11

MAIN UNIT OPERATIONS
PERIOD 2 RESULTS
January and February 1986

Date	Softening									Regeneration				
	Ion-Exchange Influent (meq/L)				Ion-Exchange Effluent (meq/L)			Resin Operating Capacity (eq/L of resin)		Recycled Brine		Fresh Brine		Total Sodium Throughput (eq/L of resin)
	Total Hardness	Calcium	Sodium	Ratio of Sodium to Total Hardness	Total Hardness	Calcium	Sodium	Total Hardness	Calcium	Sodium (meq/L)	EC (µS/cm)	Sodium (meq/L)	EC (µS/cm)	
1-01	50.1	23.1	58.7	1.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-02	49.8	23.2	62.6	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-03	55.5	22.7	65.2	1.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-04	50.3	22.9	66.1	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-05	49.8	23.5	67.8	1.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-06	50.8	23.6	69.1	1.4	7.6	2.2	100.0	0.671	0.332	NA	NA	NA	NA	NA
1-07	50.3	23.6	69.1	1.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-08	51.2	23.5	64.1	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-09	51.9	23.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-10	49.4	23.8	77.2	1.6	3.5	1.3	108.7	0.714	0.350	NA	NA	NA	NA	NA
1-11	NA	23.3	73.9	NA	9.2	2.4	102.2	NA	0.325	NA	NA	NA	NA	NA
1-12	47.8	23.3	71.7	1.5	4.8	1.0	108.7	0.668	0.347	NA	NA	NA	NA	NA
1-13	48.7	24.2	70.7	1.5	2.7	1.2	NA	NA	NA	NA	NA	NA	NA	NA
1-14	50.4	24.0	70.7	1.4	2.9	1.1	NA	NA	NA	NA	NA	NA	NA	NA
1-15	46.1	24.5	69.6	1.5	2.8	1.0	106.5	0.672	0.366	NA	NA	NA	NA	NA
1-16	NA	24.3	64.1	NA	3.2	0.9	115.2	NA	0.363	NA	NA	NA	NA	NA
1-17	NA	23.5	72.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-18	37.5	23.6	66.3	1.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-19	44.1	23.4	66.3	1.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-20	44.2	23.4	72.8	1.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-21	43.6	23.3	70.7	1.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-22	NA	23.4	76.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-23	43.5	23.3	78.3	1.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-24	44.0	24.3	77.2	1.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-25	43.5	24.1	83.7	1.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-26	44.4	23.3	84.8	1.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-27	45.1	24.1	85.9	1.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-28	45.7	25.3	85.9	1.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-29	NA	24.1	80.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-30	NA	24.3	83.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1-31	NA	24.2	90.2	NA	3.3	1.6	147.8	NA	0.352	NA	NA	NA	NA	NA
2-01	50.1	25.0	NA	NA	3.2	1.4	NA	0.730	0.367	NA	NA	NA	NA	NA
2-02	49.8	24.3	NA	NA	3.3	1.6	NA	0.721	0.353	NA	NA	NA	NA	NA
2-03	55.5	25.2	87.0	1.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-04	50.3	24.4	92.4	1.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-05	49.8	24.6	93.5	1.9	11.6	2.2	141.3	0.593	0.348	1,500.0	99,800	NA	NA	NA
2-06	50.8	26.2	92.4	1.8	10.3	1.6	141.3	0.629	0.381	1,760.9	98,800	1,652.2	100,500	15.1
2-07	50.3	24.1	93.5	1.9	10.1	2.0	123.9	0.625	0.343	3,913.0	65,600	1,913.0	72,300	32.0
2-08	51.2	24.7	107.6	2.1	11.1	2.4	158.7	0.623	0.346	1,521.7	77,400	1,934.8	75,300	13.5
2-09	51.9	25.4	116.3	2.2	12.5	2.6	171.7	0.613	0.355	1,673.9	77,200	2,173.9	77,400	14.9
2-10	49.4	24.8	95.7	1.9	15.5	2.8	121.7	0.528	0.342	1,043.5	73,400	1,478.3	73,000	9.4
2-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	72,100	NA	76,000	NA
2-12	47.8	24.6	77.2	1.6	15.0	2.3	108.7	0.510	0.346	934.8	86,500	456.5	90,800	7.7
2-13	48.7	25.5	76.1	1.6	12.5	1.8	113.0	0.563	0.369	1,065.2	81,800	1,413.0	89,400	9.5
2-14	48.4	24.2	76.1	1.6	11.4	1.7	108.7	0.575	0.350	826.1	80,600	1,326.1	90,500	7.5
2-15	46.1	24.0	84.8	1.8	13.2	1.7	106.5	0.511	0.346	978.3	80,000	1,869.6	82,100	9.2

EC = electrical conductivity.
NA = not available.

Figure 14: Resin Capacity and Calcium Leakage Resulting from Sodium Throughput in Regeneration January and Febuary, 1986



In addition, a printer was installed on the Analog computer to record the duration and time of the events performed. This printer was required for restarting the system because, during power outages of less than a second, the computer lost track of the event being performed. The power outages, which mostly occurred at night, were believed to be a result of the electrical purveyor's operations.

The IX/RO systems were shut down June 10, 1986, due to high silt density index in the feedwater to the desalting units. This condition was attributed to the changing chemistry of the San Luis Drain water as its volume was reduced by Westlands Water District in conformance with Westlands' agreement with the U. S. Department of Interior.

Period 3 results, shown in Table 13 and on Figure 15, are indicative of the various problems encountered. Sodium throughput in regeneration declined and eventually leveled off to approximately 7 equivalents of sodium per liter of resin, while the calcium leakage was high and erratic compared to previous operations. Calcium leakage ranged from a low of 4 meq/L to a high of over 11 meq/L. Other data collected in Period 3 are presented in Appendix F.

<u>Period 4 (July Through August 1986)</u>

The IX operations program was further modified in late June 1986 to provide upflow rinsing for rinsing events A and B. This modification was necessary in order to pass the complete fresh brine volume through the entire resin bed. Other modifications included expanded choice of flowrates for events 2, 3, 4, 5, and 8. The modified operation schedule is shown in Table 14.

TABLE 12

ION-EXCHANGE OPERATIONS SCHEDULE
PERIOD 3
(reverse osmosis/electrodialysis brine regeneration,
service flow at 110 gpm)

Waste brine to IX sump
Used brine to T2 or T3
Rinse to RWPS

Two-unit continuous operation
Test 1, Week 1
April 28, 1986

Event Number	Event Description	Duration (minutes)	Component Operation (valve open)		Process Flow		
			Unit 1	Unit 2	Unit	From	To
1	Recycled brine regeneration 1	10	IP 5 IV 15, 12, 7, 9, 22	IP 5 IV 115, 112, 107, 109, 122	1 2	T4 T4	IX sump IX sump
2	Recycled brine regeneration 2	32	IP 5 IV 15, 12, 7, 4, 23	IP 5 IV 115, 112, 107, 104, 123	1 2	T4 T4	T2 T3
3	Fresh brine regeneration	8	IP 3 IV 16, 13, 7, 4, 23	IP 2 IV 116, 113, 107, 104, 123	1 2	T6 T7	T2 T3
4	Rinse A	5	IP 7 IV 1, 7, 19, 23	IP 9 IV 101, 107, 119, 123	1 2	CW1 CW2	T2 T3
5	Rinse B	4	IP 7 IV 2, 7, 19, 23	IP 9 IV 102, 107, 119, 123	1 2	CW1 CW2	T2 T3
6	Rinse C	0	IP 7 IV 2, 7, 10, 22	IP 9 IV 102, 107, 110, 122	1 2	CW1 CW2	IX sump IX sump
7	Rinse D	16	IP 7 IV 2, 7, 10, 21	IP 9 IV 102, 107, 110, 121	1 2	CW1 CW2	RWPS RWPS
8	Service	180	IP 7 IV 1, 7, 11 CSOV 1	IP 9 IV 101, 107, 111 CSOV 6	1 2	CW1 CW2	CW5 CW5
9	Settling in T2 or T3	120	A 1*	A 2*	1 2	Settling in T2** Settling in T3**	
10	Set-up for regeneration to T4	28	IP 6 IV 5	IP 6 IV 105	1 2	T2 T3	T4** T4**
11	Drain	3	IV 6, 10, 21	IV 106, 110, 121	1 2	Unit 1 Unit 2	RWPS RWPS
12	Delay	32	A 1	A 2	1 2		

* Agitators are not in operation during Event 7 and part of Event 8.
Agitators are placed back into operation after Event 10 is completed during Event 8.
(During all other events, agitators are in operation.)

** To be performed during service event.

Key

A	agitator mixer	IV	ion-exchange valve
CW	clearwell	IX	ion exchange
CSOV	chlorine solenoid valve	RWPS	return water pump station
IP	ion-exchange pump	T	brine tank

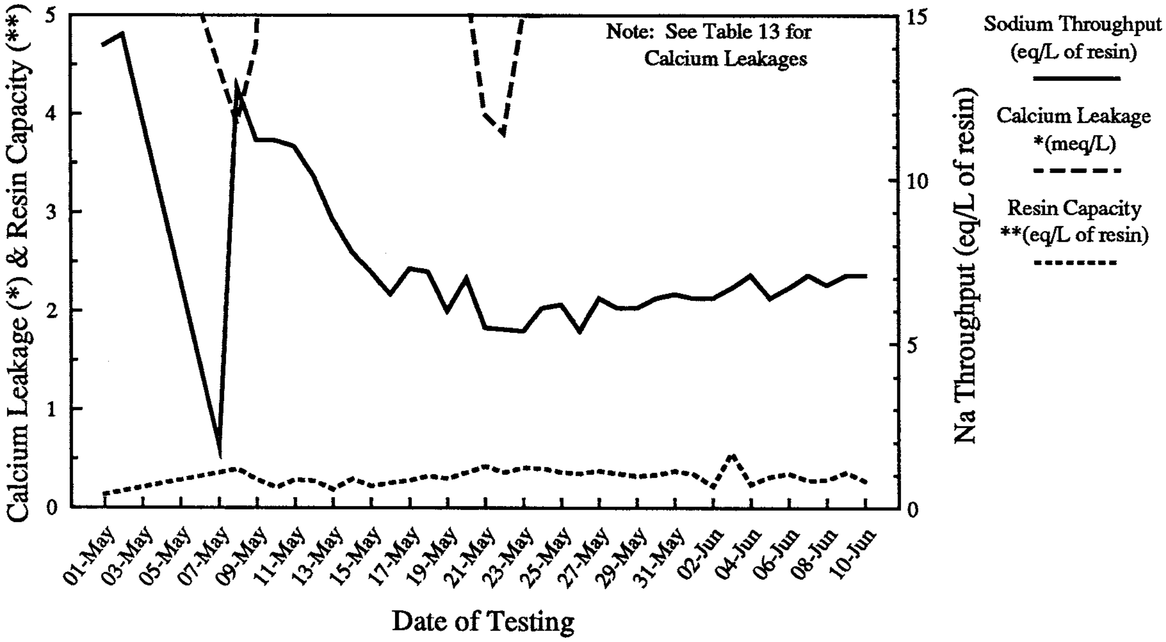
TABLE 13

MAIN UNIT OPERATIONS
PERIOD 3 RESULTS
May and June 1986

Date	Softening									Regeneration				
	Ion-Exchange Influent (meq/L)				Ion-Exchange Effluent (meq/L)			Resin Operating Capacity (eq/L of resin)		Recycled Brine		Fresh Brine		Total Sodium Throughput (eq/L of resin)
	Total Hardness	Calcium	Sodium	Ratio of Sodium to Total Hardness	Total Hardness	Calcium	Sodium	Total Hardness	Calcium	Sodium (meq/L)	EC (μS/cm)	Sodium (meq/L)	EC (μS/cm)	
5-01	49.2	27.0	87.0	1.8	39.8	8.1	178.3	NA	NA	1,956.5	75,700	2,130.4	73,400	NA
5-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	2,000.0	76,700	2,173.9	74,400	15.2
5-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5-06	NA	NA	89.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5-07	NA	NA	91.3	NA	NA	NA	89.1	NA	NA	134.8	68,100	1,217.4	74,700	2.0
5-08	50.0	26.7	91.3	1.8	23.2	3.9	128.3	0.415	0.352	1,391.3	65,700	2,260.9	82,000	13.4
5-09	40.8	27.2	93.5	2.3	21.4	4.7	143.5	0.300	0.348	1,173.9	57,100	2,347.8	77,600	11.8
5-10	50.2	27.5	95.7	1.9	36.2	8.0	139.1	0.217	0.302	1,173.9	54,000	2,434.8	78,000	11.8
5-11	49.8	26.5	100.0	2.0	30.6	6.0	137.0	0.297	0.317	1,130.4	52,000	2,565.2	78,000	11.6
5-12	50.8	27.0	102.2	2.0	32.1	6.3	137.0	0.289	0.321	1,043.5	49,000	2,782.6	77,000	10.6
5-13	50.0	27.1	97.8	2.0	37.2	7.2	137.0	0.199	0.308	956.5	48,000	2,304.3	77,000	9.3
5-14	50.6	27.7	93.5	1.8	30.7	6.8	123.9	0.308	0.324	826.1	44,200	2,087.0	65,400	8.2
5-15	51.2	27.3	95.7	1.9	36.3	7.2	119.6	0.230	0.311	782.6	44,000	1,869.6	61,000	7.6
5-16	50.3	29.3	82.6	1.6	33.4	8.3	100.0	0.263	0.326	652.2	47,600	1,652.2	71,000	6.9
5-17	51.2	27.7	87.0	1.7	32.1	6.8	100.0	0.295	0.324	739.1	44,500	1,782.6	67,700	7.7
5-18	52.6	28.0	NA	NA	30.4	6.0	104.3	0.344	0.340	739.1	45,000	1,695.7	64,000	7.6
5-19	51.4	27.2	73.9	1.4	31.3	6.8	82.6	0.312	0.315	652.2	46,000	1,043.5	68,000	6.3
5-20	NA	NA	73.9	NA	NA	NA	87.0	NA	NA	652.2	49,600	2,173.9	112,700	7.3
5-21	51.2	27.5	100.0	2.0	22.6	4.0	126.1	0.443	0.364	521.7	50,100	1,608.7	89,100	5.8
5-22	52.3	27.1	106.5	2.0	27.6	3.8	139.1	0.382	0.360	NA	53,900	NA	92,800	NA
5-23	51.6	26.5	100.0	1.9	23.8	5.0	126.1	0.430	0.333	565.2	58,300	1,130.4	71,800	5.7
5-24	50.4	26.5	104.3	2.1	22.8	5.0	130.4	0.427	0.333	608.7	56,600	1,521.7	101,500	6.4
5-25	47.2	23.6	119.6	2.5	22.6	5.2	143.5	0.381	0.285	608.7	63,000	1,652.2	107,000	6.5
5-26	47.6	24.4	117.4	2.5	23.8	5.4	137.0	0.369	0.294	521.7	64,000	1,565.2	112,000	5.7
5-27	47.6	23.7	106.5	2.2	23.2	5.4	126.1	0.395	0.295	652.2	60,900	1,521.7	107,500	6.7
5-28	46.6	22.5	113.0	2.4	23.6	5.6	128.3	0.372	0.274	608.7	62,800	1,565.2	109,100	6.4
5-29	45.8	21.5	110.9	2.4	24.6	11.5	121.7	0.343	0.162	608.7	63,900	1,521.7	112,300	6.4
5-30	46.2	23.7	113.0	2.4	24.2	6.0	143.5	0.356	0.286	652.2	67,100	1,565.2	106,800	6.8
5-31	48.8	22.5	115.2	2.4	24.4	6.0	150.9	0.395	0.266	652.2	69,700	1,608.7	108,700	6.8
6-01	51.4	21.5	137.4	2.7	29.0	10.0	155.2	0.363	0.186	652.2	68,800	1,565.2	97,600	6.8
6-02	52.0	22.5	135.2	2.6	37.4	10.0	148.7	0.236	0.202	652.2	75,300	1,565.2	106,600	6.8
6-03	55.2	23.5	135.2	2.4	19.0	7.0	150.9	0.586	0.267	695.7	77,300	1,434.8	107,400	7.0
6-04	46.6	20.5	135.2	2.9	30.8	5.0	159.6	0.256	0.251	739.1	79,100	1,521.7	108,300	7.4
6-05	48.8	19.5	144.3	3.0	28.2	8.0	157.4	0.333	0.186	652.2	75,200	1,565.2	107,800	6.8
6-06	51.0	21.0	144.3	2.8	28.2	7.5	157.4	0.369	0.219	695.7	67,700	1,521.7	88,400	7.1
6-07	47.2	23.0	148.7	3.2	29.2	9.0	159.6	0.291	0.227	739.1	68,800	1,521.7	89,200	7.4
6-08	48.6	22.5	146.5	3.0	30.2	11.5	166.5	0.298	0.178	695.7	70,800	1,565.2	94,800	7.1
6-09	53.8	20.5	139.6	2.6	30.0	8.0	159.6	0.385	0.202	739.1	72,900	1,521.7	98,000	7.4
6-10	51.6	35.0	128.7	2.5	33.8	9.0	150.9	0.288	0.421	739.1	74,700	1,521.7	97,600	7.4

EC = electrical conductivity.
NA = not available.

Figure 15: Resin Capacity and Calcium Leakage Resulting from Sodium Throughput in Regeneration May and June, 1986



IX Unit 2 was restarted during the latter part of July when the silt density index was lowered to acceptable levels by the clarification/filtration system. The IX system was operated according to the new schedule. The process scheme was IX Unit 2 to RO Unit 2 to EDR and the EDR's reject brine to the fresh brine tank as shown on Figure 16. The process scheme did not change until August 5, 1986, when RO Unit 1 was brought on-line. Figure 17 shows the changes that occurred when RO Unit 1 was introduced. On August 8, 1986, the process scheme was returned to the previous scheme when RO Unit 1 was shut down to repair a pump seal. These systems remained in operation until August 20, 1986, when the system was completely shut down because of high silica and silt density index levels.

Results of Period 4 operations are shown in Table 15 and graphed on Figure 18. Calcium leakage remained around 1.0 meq/L for the entire period except from August 5 to 10, 1986. During this period, calcium leakage rose to as high as 4.0 meq/L, due to the phasing in of RO Unit 1 and the reduction of the sodium content of the regenerant brine.

Other information -- including data from operation logs, daily chemical analyses, and test plans concerning Period 4 operations -- is located in Appendix G.

TABLE 14

ION-EXCHANGE OPERATIONS SCHEDULE
PERIOD 4
(default durations and flows,
reject brine regeneration,
upflow rinse)

Waste brine to IX sump
Used brine to T2 or T3

Rinse to San Luis Drain

Event Number	Event Description	Duration* (minutes)	Component Operation (valve open)		Process Flow		
			Unit 1	Unit 2	Unit	From	To
1	Recycled brine regeneration 1	13	IP 5, A 1 IV 15, 12, 7, 9, 22	IP 5, A 2 IV 115, 112, 107, 109, 122	1 2	T4 T4	IX sump IX sump
2	Recycled brine regeneration 2	40	IP 5, A 1 IV 15, 7, 4, 23 **	IP 5, A 2 IV 115, 107, 104, 123 **	1 2	T4 T4	T2 T3
3	Fresh brine regeneration	9	IP 1, A 1 IV 17, 7, 4, 23, 39m **	IP 1, A 2 IV 18, 107, 104, 123, 139m **	1 2	T1 T1	T2 T3
4	Rinse A, upflow	6	IP 7, A 1 IV 3, 7, 4, 23 **	IP 9, A 2 IV 103, 107, 104, 123 **	1 2	CW1 CW2	T2 T3
5	Rinse B, upflow	5	IP 7, A 1 IV 3, 7, 4, 23 **	IP 9, A 2 IV 103, 107, 104, 123 **	1 2	CW1 CW2	T2 T3
6	Rinse C	5	IP 7, A 1 IV 1, 7, 10, 21	IP 9, A 2 IV 101, 107, 110, 121	1 2	CW1 CW2	RWPS RWPS
7	Rinse D	9	IP 7 IV 2, 7, 10, 21	IP 9 IV 102, 107, 110, 121	1 2	CW1 CW2	RWPS RWPS
8	Service	120	IP 7 IV 7, 11 ** CSOV 1	IP 9 IV 107, 111 ** CSOV 6	1 2	CW1 CW2	CW3 CW4
9	Settling in T2 or T3	50			1 2	Settling in T2 *** Settling in T3 ***	
10	Set-up for regeneration to T4 from T2 or T3	35	IP 6 IV 5	IP 6 IV 105	1 2	T2 T3	T4 *** T4 ***
11	Drain	3	IV 6, 10, 21 A 1	IV 106, 110, 121 A 2	1 2	Unit 1 Unit 2	RWPS RWPS
12	Delay	0	A 1	A 2			

* Durations based upon two-unit operation for one bed volume of brine produced during service and flows of 200, 150, 75, 200, and 230 for Events 2, 3, 4, 5, and 8, respectively (default flows and durations). See operation instructions for current flows and durations. Process water EC at 7,500 µS/cm.

** Flow variables:
Events 2, 3, 4, and 5: IV 14 or 114 for 75 gpm or IV 13 or 113 for 150 gpm or IV 12 or 112 for 200 gpm.
Event 8: IV 1 or 101 for 110 gpm or IV 2 or 102 for 230 gpm.

*** To be performed during service event.

<u>Key</u>

A	agitator mixer	IX	ion exchange
CW	clearwell	m	manual
CSOV	chlorine solenoid valve	RWPS	return water pump station
IP	ion-exchange pump	T	brine tank
IV	ion-exchange valve		

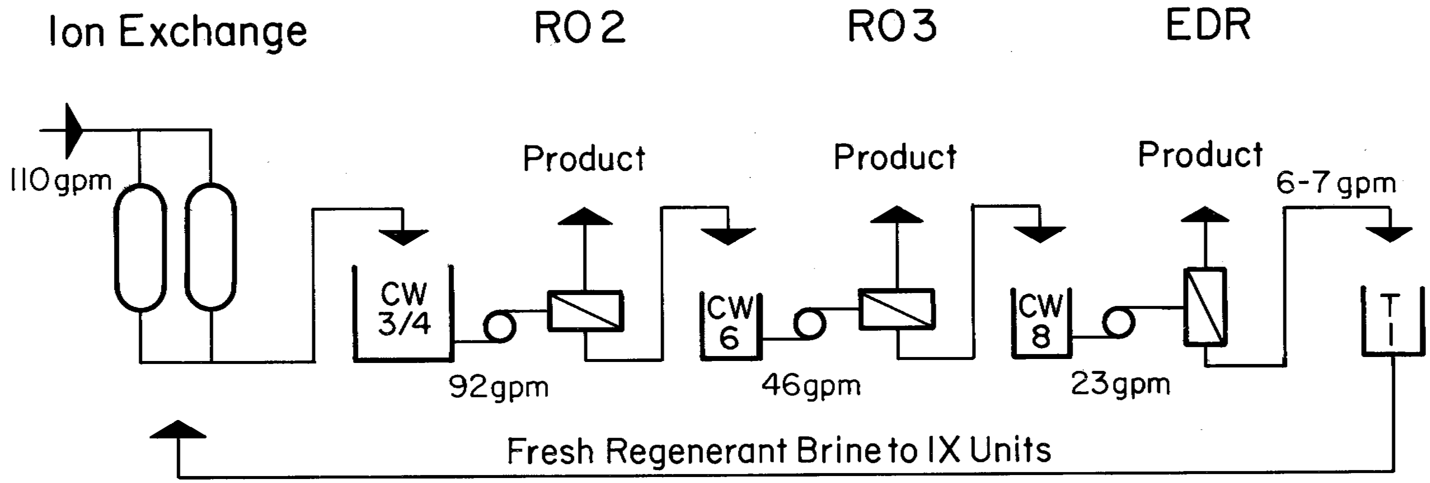


Figure 16. Flow Schematic IX to RO 2 to RO 3 to EDR

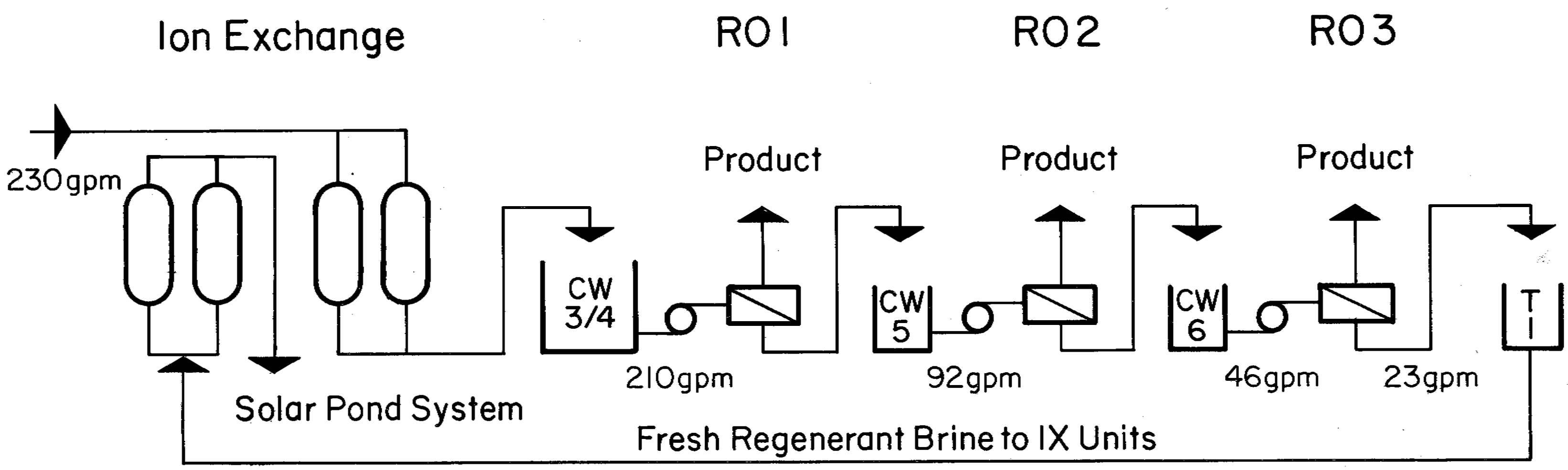


Figure 17. Flow Schematic IX to RO 1 to RO 2 to RO 3

TABLE 15

MAIN UNIT OPERATIONS
PERIOD 4 RESULTS
July and August 1986

Date	Softening									Regeneration				
	Ion-Exchange Influent (meq/L)				Ion-Exchange Effluent (meq/L)			Resin Operating Capacity (eq/L of resin)		Recycled Brine		Fresh Brine		Total Sodium Throughput (eq/L of resin)
	Total Hardness	Calcium	Sodium	Ratio of Sodium to Total Hardness	Total Hardness	Calcium	Sodium	Total Hardness	Calcium	Sodium (meq/L)	EC (µS/cm)	Sodium (meq/L)	EC (µS/cm)	
7-16	30.8	17.5	57.6	1.9	*									
7-17	26.4	14.0	51.1	1.9	*									
7-18	28.0	14.0	47.4	1.7	NA	1.3	NA	NA	0.274	NA	NA	NA	NA	NA
7-19	14.6	15.5	43.0	2.9	*									
7-20	NA	12.0	39.6	NA	*									
7-21	28.2	32.0	38.5	1.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7-22	29.6	9.5	32.8	1.1	15.6	6.0	71.3	0.301	0.075	739.1	85,200	1,260.9	108,900	7.4
7-23	20.0	12.3	29.3	1.5	14.4	5.5	48.7	0.120	0.145	652.2	19,300	1,260.9	8,600	6.7
7-24	17.2	11.0	28.3	1.6	3.2	0.7	44.3	0.301	0.221	652.2	81,000	1,217.4	10,100	6.7
7-25	19.4	9.5	26.1	1.3	2.6	1.0	37.2	0.361	0.183	521.7	70,300	565.2	51,400	4.9
7-26	20.4	9.0	30.4	1.5	2.8	1.3	44.3	0.378	0.167	565.2	65,800	521.7	44,900	5.2
7-27	19.2	8.0	35.0	1.8	3.6	1.5	42.2	0.335	0.140	478.3	60,400	478.3	40,800	4.5
7-28	16.6	7.5	29.3	1.8	2.8	1.0	37.6	0.297	0.140	565.2	70,200	434.8	40,800	5.1
7-29	13.5	7.5	27.2	2.0	2.8	1.0	40.0	0.230	0.140	434.8	56,800	478.3	38,400	4.1
7-30	11.2	6.5	19.2	1.7	2.6	1.0	28.8	0.185	0.118	347.8	44,700	695.7	36,100	3.6
7-31	22.4	12.0	27.2	1.2	2.8	1.0	28.9	0.421	0.236	369.6	52,900	434.8	37,400	3.5
8-01	3.6	2.0	24.8	6.9	2.8	1.0	42.2	0.017	0.021	291.3	37,400	391.3	38,100	2.7
8-02	10.8	6.0	31.7	2.9	2.6	1.0	28.3	0.176	0.107	347.8	37,600	413.0	39,500	3.2
8-03	10.4	6.0	12.4	1.2	1.8	1.0	33.3	0.185	0.107	347.8	41,200	478.3	40,700	3.3
8-04	11.6	6.5	14.8	1.3	1.8	1.0	21.5	0.211	0.118	347.0	42,700	478.3	41,000	3.3
8-05	10.4	6.5	12.4	1.2	7.2	4.0	48.7	0.069	0.054	245.9	31,000	184.3	17,600	2.0
8-06	11.4	5.5	13.5	1.2	2.2	1.5	55.4	0.198	0.086	197.6	23,300	193.3	17,200	1.7
8-07	11.2	7.0	23.7	2.1	2.4	1.5	49.8	0.189	0.118	109.8	23,900	391.3	20,200	1.5
8-08	11.0	7.0	NA	NA	3.4	3.5	NA	0.163	0.075	167.0	21,400	217.4	20,800	1.6
8-09	12.4	15.5	23.7	1.9	4.6	2.5	31.1	0.168	0.279	153.9	27,100	478.3	29,700	1.9
8-10	11.8	6.5	27.2	2.3	3.6	1.0	39.6	0.176	0.118	NA	NA	NA	NA	NA
8-11	11.4	6.0	26.1	2.3	NA	NA	NA	NA	NA	326.1	17,600	826.1	31,200	3.7
8-12	13.6	6.5	26.1	1.9	3.6	1.0	36.1	0.215	0.118	326.1	17,300	847.8	32,200	3.7
8-13	11.6	6.0	NA	NA	4.2	1.0	NA	0.159	0.107	260.9	24,300	413.0	31,100	2.5
8-14	13.6	6.5	28.3	2.1	2.4	1.0	39.6	0.241	0.107	NA	NA	NA	NA	NA
8-15	12.4	6.5	NA	NA	2.6	1.0	NA	0.211	0.118	282.6	32,500	391.3	29,900	2.7
8-16	13.4	7.0	24.8	1.8	2.4	1.5	31.7	0.236	0.118	304.3	33,200	369.6	30,200	2.8
8-17	12.6	14.5	30.4	2.4	3.2	1.3	38.5	0.202	0.285	304.3	30,900	347.8	27,300	2.7
8-18	13.6	7.0	NA	NA	3.2	1.3	NA	0.224	0.124	239.1	29,400	304.3	25,620	2.2
8-19	14.6	7.0	NA	NA	4.6	1.5	NA	0.215	0.118	144.8	17,900	326.1	25,900	1.6
8-20	12.4	7.0	NA	NA	*									
8-21	13.4	7.0	NA	NA	*									

*IX system off.

EC = electrical conductivity.
NA = not available.

Figure 18: Resin Capacity and Calcium Leakage Resulting from Sodium Throughput in Regeneration July and August, 1986